4 What control measures do we need for compost production and use

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In short:

- The management of the composting process depends on the periodical control of temperature, moisture content and oxygen concentration.
- The determination of the quantities of ammonium (NH_4-N), nitrite (NO_2-N) and nitrate (NO_3-N) in the compost allows the evaluation of its maturity, the quality of the composting process and of the storage of the product, and the risk of N immobilization or release in the soil.
- Plant phytotoxicity tests can assess the maturity and the quality of the produced compost.
- The choice of the appropriate compost, application strategy and use, should be guided by analyses of pH-value, salinity, intensity of colour extract and nutrient content.

As described in chapter 2, there are various composting methods as well as a range of compost types. However, the biological process, described in chapter 3, is similar and independent of the technology used. Hence, the relevant parameters that allow the control of the composting process and the quality of the produced compost are basically similar for all systems. These parameters are important, in combination with a few others, for the determination of the quality of the composts produced and the selection of the right compost for the defined application. It is also important to produce a protocol for the process.

4.1 Production control measures

4.1.1 Temperature

Due to the very intensive microbiological activity at the beginning of the composting process, the temperature in the windrow increases up to 60°C or more (Figure 4.1). After some time, the temperature decreases again and the composting process goes from the decomposition phase (Figure 4.1, yellow part) to the maturation phase (Figure 4.1, white part).

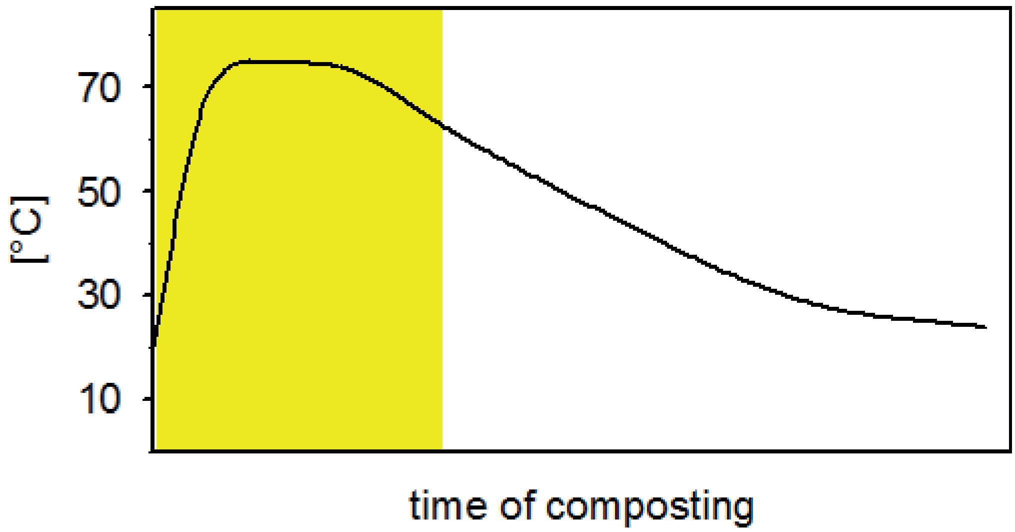

Figure 4.1 *Theoretical evolution of the temperature in the compost piles during the composting process (Graph: Ulrich Galli).*

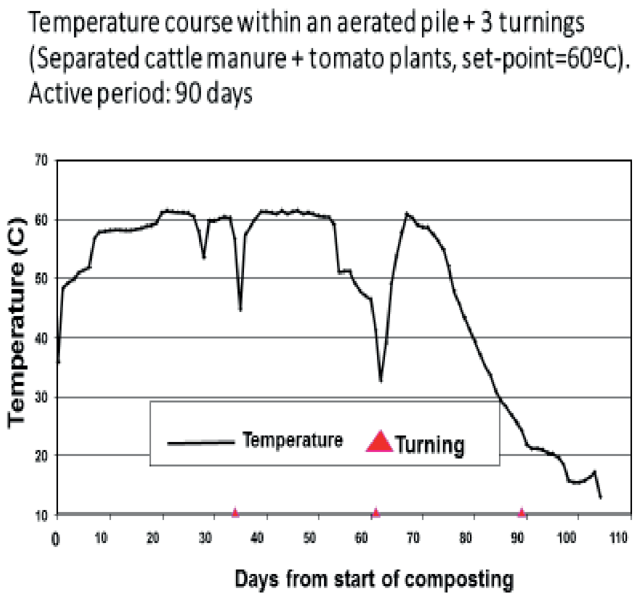

Figure 4.2 *Evolution of the temperature in a controlled compost pile during a typical composting process (Graph: Michael Raviv).*

The temperature level reached depends of the reactivity of the starting mixture and on the control means. Optimally, the temperature should reach 60 - 65°C. For a better biological quality of the compost, a temperature as high as 70 or 80°C is not desirable. This happens when the starting mixture is too rich in N combined with sufficient oxygen and not enough moisture content. A very high temperature in the pile limits the diversity of the microorganisms in the composting material and decreases the decomposition rate.

Under controlled conditions (e.g. when temperatures are measured daily and turnings are done in order to maintain the temperatures below a setpoint), the process is quite different. A typical optimal thermophilic temperature (e.g. 60°C) is maintained by frequent turnings (or aeration, in case of the forced aeration composting system). Under such conditions, mass extinction of thermophilic microorganisms does not occur, leading to a longer thermophilic phase (typically 6-8 weeks), a better control of pathogen and weed seeds and the avoidance of ashing. The result is a compost of higher quality. Turning ensures better homogeneity of the compost, by bringing outer, cooler layers into the core of the pile.
The elevation of the temperature during the composting process is essential to ensure the destruction of weeds and of pathogens that are usually present in the starting mixture (see chapter 5). For this to happen, the temperature has to reach at least 55°C during three weeks or 65°C during one week, and the compost pile has to be turned at least twice during this period.
An insufficient temperature can be observed when the starting mixture is too rich in carbon, too dry, too wet or when there is insufficient oxygen present in the pile. Attaining a sufficient temperature should not be a problem with correct management of the process.
The management of the moisture content in the pile is also an important factor that influences the evolution of the temperature to some extend (see below).

Figure 4.3 *Temperature measurement is important to control the composting process.*

The evolution of the temperature is a good indicator of the quality of the composting process. Normally, the temperature increases relatively rapidly at the start of the process, and then slowly decreases. After turning the compost pile, the temperature drops and immediately increases again. This is because the turning operation redistributes the intermediate decomposition molecules and optimizes the oxygen distribution in the pile, hence triggering the biological activity in the pile. The evolution of the average temperature is relatively steady if the evolution of the composting process is going well. An abrupt decrease in temperature is a sign that something is wrong in the process, such as insufficient or excess moisture, or the limited presence of available nitrogen.
The evolution of the temperature has to be recorded periodically, preferably daily or at least three times per week. It is important to measure the temperature correctly: at the hot spot (at a depth of 40-50 cm, see Figure 3.3) at 3 to 10 spots of the pile (depending on the pile dimension). These data are important as they prove the correct natural hygienization of the compost (see chapter 5). For larger compost piles, thermometers (or preferably sensors connected to data loggers) should be inserted in the middle of the pile, at half the height.

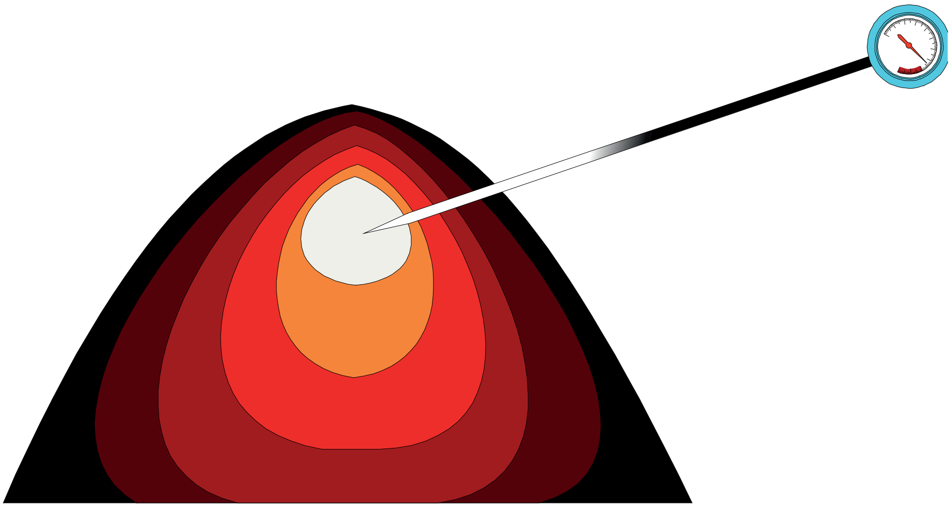

Figure 4.4 *The temperature of the compost pile has to be measured at the central hot spot (Graph: Ulrich Galli).*

The duration of the composting process is not relevant as a quality parameter. The complete process can take between 10 weeks and 6 months depending on the input material, the composting system and the intensity of process management.

4.1.2 Moisture content

As explained in Chapter 3, microorganisms are only active when sufficient moisture is available. Excessive moisture, on the other hand, can lead to undesirable anaerobic processes which can even arrest the composting process. Water evaporation from the pile is important to prevent excessive temperatures as well as optimizing microbial activity. The quantity of water needed to maintain optimal moisture in the compost pile varies during the process. Water evaporation is important because of the high temperature of the pile. This evaporation is enhanced by intensive compost turning or active aeration of the pile. Maintaining optimal moisture content is therefore crucial during this period. Later, during the curing phase, much less water is lost, and water over-supply can quickly lead to excessive high moisture levels in the compost.
To obtain a compost of homogenous quality, moisture distribution has to be homogenous in the pile. This is another reason for turning the compost pile periodically.
The moisture content of the external layer of the compost pile (0-20 cm) is generally different from that of the rest of the pile. Therefore, moisture content should be determined using test samples from inside the pile (typically 40-50 cm deep).
Optimal moisture content for the composting process roughly corresponds to a dry matter content of about 50%. The moisture content can be estimated using the so-called fist test (Figure 4.5): take a handful of compost and squeeze it as strongly as possible between the fingers. If water flows out, the compost is too wet. Open the fingers. If the compost ball disintegrates itself, the compost is too dry. If the compost ball stays compact, the compost moisture is optimal.

Figure 4.5 *Fist test to control the humidity of compost during the composting process. From left to right: too wet, optimal, and too dry.*

4.1.3 Oxygen content

To have an optimal composting process, the oxygen content in the atmosphere of the compost pile has to be at least 3 to 5 %. It is also important to pay attention to the distribution of the oxygen in the pile, making sure that each piece of material is supplied with enough oxygen. Here, it is particularly important to avoid the formation of clods using efficient compost turning; otherwise, anaerobic conditions can be present in these chunks. To be sure that the aerobic conditions are present in the whole pile, we recommend a measurement of the methane (CH_4 content within the pile – this can be carried out using a portable gas analyzer). The absence of CH_4 is an indication of a homogenous distribution of oxygen in the pile.
The oxygen demand is much more important during the thermophilic phase of the composting process. Later, when the microbiological activity decreases, the oxygen demand decreases strongly and continues at a low level. It is important to constantly maintain a minimal level of oxygen in the compost to ensure high biological quality, including during the storage of the mature products.

4.1.4 Available nitrogen

The nitrogen (N) in composts is mainly present as organic nitrogen, which is less available to plants. However, the greatest proportion of N taken up by plants is in the form of mineral-N. 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 is evaluated during the composting process (Figure 4.6, see also chapter 3).
NH_4-N is the first form of mineralized nitrogen found in compost when the organic material is decomposed. NH_4-N is soluble in water and when the moisture content becomes too low, the NH_4-N is lost as it will be formed into gaseous NH_3 (ammonia).
NO_3-N. During the curing process, nitrification is ongoing and the NH_4-N is transformed into NO_3-N. If oxygen starvation happens during the curing phase or the storage, bacteria can use the oxygen of NO_3 and transform it back to nitrite (NO_2; toxic for the plants) or to nitrous oxide (N_2O; strong greenhouse gas).
NO_2-N is an intermediate, phytotoxic product arising during the nitrification. It can also be a result of the denitrification process by oxygen starvation at the end of the curing process or from compost storage.

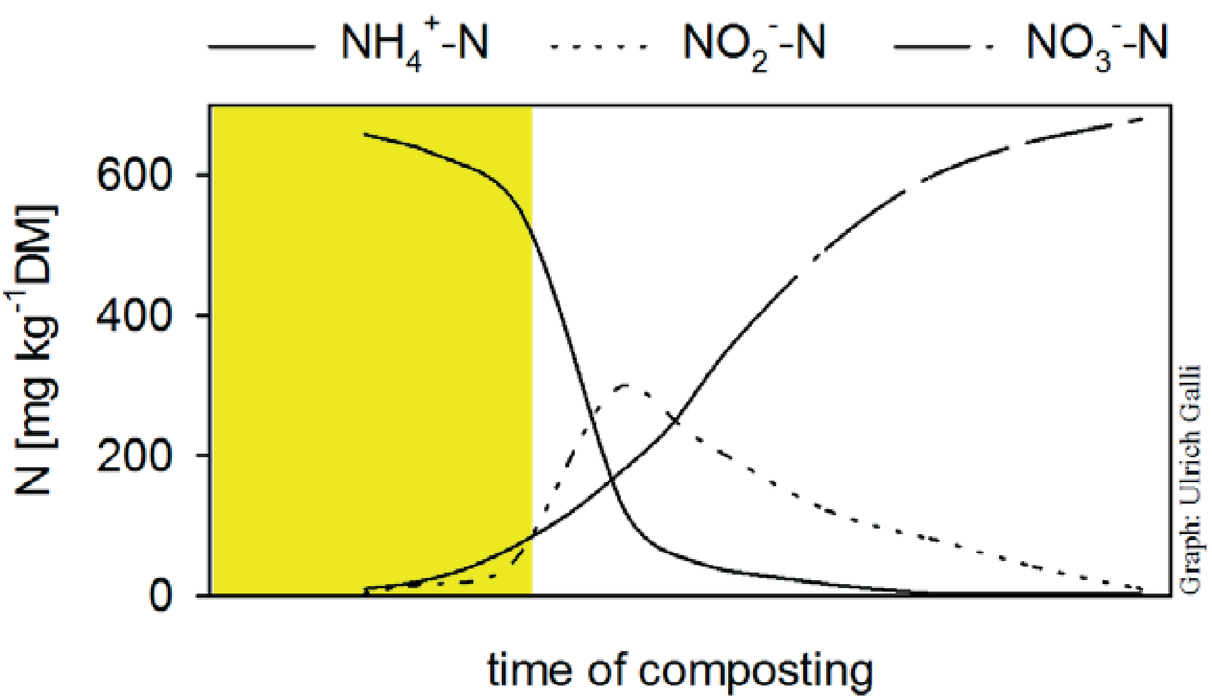

Figure 4.6 *Evolution of the mineralized forms of nitrogen in the compost piles during the composting process (Graph: Ulrich Galli).*

If the composting mixture is carbon-rich or when the composting process is inappropriately managed (e.g. low moisture content), it is possible to find almost no mineral N in the compost. The N is immobilized in the microbial community or is lost as NH_3. In this case, the composting process can become blocked because of lack of available N. When such compost is applied, it is also possible that N immobilization happens in field, and the plant growth can then be inhibited if no other sources of nitrogen are added. So, the values of mineralized forms of N are essential parameters to management of the composting process on one hand and the identification of appropriate uses for compost products on the other.
NH_4-N, NO_2-N and NO_3-N can be easily analysed with different quick tests in 0.01 M $CaCl_2$ or KCl compost extracts. These tests can be performed on site by the composting manager. The interpretation of the obtained measurements is described in Table 4.1. It is not the absolute individual values that are the most important, but the relationships between the different forms of mineralized nitrogen.

Table 4.1
Interpretation of the signification of the quantity of the different forms of mineralized nitrogen forms in compost.

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)

4.1.5 Maturity level

Several parameters give information on the maturity level of the compost. Principally, mature compost is stable and biologically less active compared to a young one. This means that the temperature of the compost does not rise anymore after compost turning, and also that the respiratory activity is low. The C/N ratio of mature compost is about 15.
A good indicator for the maturity level of compost is the NO_3-N/ N_{min} ratio. As describe above, young compost contains mainly only NH_4 as mineralized N. Mature compost contains almost only NO_3 as mineralized N. Based on results of Swiss studies[1, 2], we recommend the use of the NO_3-N/N_{min} ratio as a reliable maturity parameter. These analyses should be done just before using the compost, and shortly after sampling. In the Netherlands, the common test is based on Oxygen Uptake Rate (OUR[6]). An even more accurate method to measure heat generation by the compost is through the use of microcalorimeter[7].

4.2 Use of control measures

4.2.1 Maturity level and phytotoxicity

When the composting process is correct, different parameters indicate the maturity level of compost: the reduction of pile temperature, the reduction in oxygen consumption, and an odor progression from NH_3 to an earthly smell similar to a forest soil. This is caused by geosmin, a compound produced by actinomycetes[8].
In addition to the observation of the compost with our own senses (odor, structure, etc.), two analyses of parameters can be recommended for the practice: the determination of the NO_3-N/N_{min}–ratio (see 4.1.5) and the phytotoxicity test. The characterization of these two parameters can be easily performed at the compost plant itself, and the information gained is especially relevant for the practical use of the compost.

4.2.1.1 NO3-N/Nmin–ratio

As described above, the mineralized forms of N are evaluated during the curing process. Hence, the NO3-N/N_{min}–ratio is a good indicator of the effective maturity of the compost, and gives important information about the possible application target of the compost. The value of this ratio is an important predictor of whether the compost will provide nitrogen to the plant or conversely, immobilize the nitrogen present in the soil. Using this value, plant growers can develop a strategy of nitrogen fertilization:

- NO_3-N/N_{min}–ratio < 0.2: young compost, with risk of nitrogen immobilization in the field if its carbon content is important (e.g. lignin rich compost). Not recommended for plants with high need for N. Can be used as mulch in some cases.
- NO_3-N/N_{min}–ratio between 0.2 and 0.8: compost is in curing phase. Can be used in field culture.
- NO_3-N/N_{min}–ratio > 0.8: mature compost. Can be used in substrates and planting holes.
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4.2.1.2 Phytotoxicity tests

A high salt content in the composting mixture may cause phytotoxicity (see 4.2.1.6). In addition, in the first phase of the decomposition of organic material, other toxic compounds may form. As a result, young composts are initially phytotoxic. During the curing phase, these toxic molecules are transformed into harmless compounds and the compost becomes more compatible for the plants. However, if the curing phase or the storage is not optimally managed (mainly due to oxygen deficiency), toxic compounds can be formed and the compost becomes phytotoxic again. The degree of phytotoxicity depends also on the plant to be grown on the compost-amended soil: some species are very sensitive, whereas others are less sensitive. For some plants, high salt content can also be a cause of phytotoxicity. Therefore, the best way to characterize the phytotoxicity risk is to perform tests using plants.
Simple tests can be done comparing germination rates of a given seed type in both compost and potting soil. Garden cress (*Lepidium sativum*) is considered as a very suitable plant to do this (Figure 4.7).

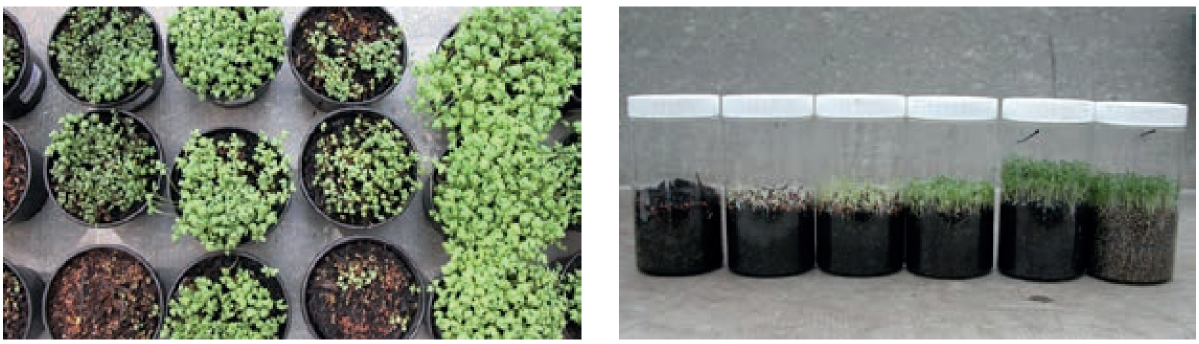

Figure 4.7 *Phytotoxicity tests to assess the compatibility of composts with plants.*
Left: open cress test. Right: closed cress test.

- In the open cress test (the growth of cress in pots (Ø 10 cm) filled with compost is compared with its growth in potting soil), the cress is not really sensitive and a bad result (plant weight < 50% of those in potting soil) indicates an important phytotoxicity problem.
- In the closed cress test (PVC boxes (1 litre) are half-filled with compost potting soil, cress is sown in it, and then the boxes are closed hermetically; the length of the roots in compost and in potting soil is then compared). The test is very sensitive, and if the results are positive (roots length > 70% of those in potting soil), the compost can be used for all applications (also for substrate production).

In order to shorten the duration of the phytotoxicity test, while still exposing the plants to the compost itself and not an extract, a phytotoxicity test that was recently modified[9] is proposed. This gives reliable results within 48 hours.

4.2.1.3 Heavy metals

Heavy metals are present in the environment and are also absorbed by the plants. The presence of a modest quantity of heavy metals in the composts is therefore acceptable. However, the quantity of heavy metals in the compost depends on the quality of the input material. For this reason, composting of municipal solid waste should only use source separated organic waste. The maximum permitted level of heavy metals in compost for organic use are indicated in Table 4.2.

Table 4.2
Maximum allowed heavy metals contents of compost for use in organic agriculture in Europe.

Heavy metal	Maximum value [g/t DM]
Lead (Pb)	45
Cadmium (Cd)	0.7
Copper (Cu)	70
Nickel (Ni)	25
Mercury (Hg)	0.4
Zinc (Zn)	200
Chrome (Cr)	70
Chrome (IV)	0

Heavy metal level in compost should be periodically analyzed according to standard analysis methods recognized by the authorities (see chapter 2).

4.2.1.4 Nutrient contents

The nutrient content of the input materials can vary greatly. Woody materials are generally much less concentrated in nutrients than lignin-poor material. Consequently, the nutrient contents in different composts can vary by factor of 3 to 4. So when using compost, it is essential to analyse the nutrient content of the specific compost to be able to calculate the nutrient balance, and not to use average values taken from the literature (see chapters 1 and 2).

4.2.1.5 pH-value

The pH-value of compost is usually relatively high (7.2 to 8.5). The pH-value is influenced by the composting process. At the start of the composting process, the pH is relatively low because of the presence of organic acids then, pH rises with the increase of the NH_4-content. Young composts thus have a high pH-value (above 8). During nitrification, the pH-value decreases. Thus mature composts usually have pH-values under 8. Because of the dynamics of the pH value, pH has to be measured periodically.
Common composts have a pH above 7. Therefore, the use of compost is not appropriate for acidophilic plants like blueberries and Rhododendron.

When using compost in plant growing media, it is possible to use elementary sulphur (S) to lower the pH-value of the media. Another possibility is the use of a significant fraction of acidic feedstocks such as olive pomace, orange peel, etc.

4.2.1.6 Salt content

Like the nutrients, salt content can greatly vary between different composts. Salt content is largely influenced by the input material, but also by the composting process. The latter is the result of the mineralization of the organic matter and of the building up of the humus compounds.
Salt content can be a limiting factor, depending on the type of crop grown. Salt content is a generic term which covers a great number of substances. Some of these are not essential for the plants and can be harmful rather than useful, like NaCl (table salt). Other salts, like the mineralized forms of N are important for the growth of the plant. Not only is the salt quantity itself important, but also the quantities of plant relevant salts like NH_4-N and NO_3-N.
An important point to consider when interpreting the salt content of compost is the extraction method used to determine it, as well as the units of measurement. Depending on the country, the water/compost ratio used to perform the compost extraction can vary greatly, and so the results obtained are not directly comparable. In some cases, the salinity is expressed as electrical conductivity in the extraction solution, and in other cases it is recalculated as g $KCl_{equivalent}$ per compost quantity (for example per g DM). This point needs to be absolutely considered when interpreting the salt content of the compost.

4.2.1.7 Intensity of colour extract

The colour intensity of compost water extract is important for the use of compost as a component in plant media. For example, if compost with a dark colour extract is used in a flower pot, there is a risk that can result in an undesirable coloration of the house wall or soil.
The water extract of young lignin-rich compost is dark, and its colour becomes lighter with increasing maturity. This is because the humus molecules present in young composts are small and soluble in water. During the maturation, microorganisms construct more complex humus molecules which are no longer soluble, thus making the extract lighter. The darkness of the extract of young compost also depends on the composition of the starting mixture.

Figure 4.7 *The colour of water extract can greatly vary between different composts. It can be a limiting factor for the production of culture media.*

4.2.1.8 Pathogens and weeds

Input organic material can contain pathogens and weed seeds. However, these are destroyed by a well-managed composting process. It is absolutely crucial to be certain that these pathogens and weed seeds are effectively inactivated before using the compost to avoid all risk of contamination of the soil in which the compost is used.
Three parameters are important for the natural sanitation of organic waste during the composting process: the temperature, the intermediate chemicals compounds resulting from the decomposition of the organic waste that are toxic to the pathogens, and the biological control of the pathogens by beneficial microorganisms.

The presence of weed seeds in compost can be assessed with germination tests, although these tests can be rather labour-intensive. It is much more difficult to assess the absence of pathogens, because the number of the possible harmful organisms is high, and it is not possible to test for all of them. A pragmatic solution is to control the temperature evolution during the composting process, as well as to guarantee a sound operation management that avoids recontamination of the mature compost with infested fresh waste.
In conclusion, a compost which had a temperature >55°C during at least three weeks or >65°C during one week is to be considered harmless from a hygienic point of view providing the compost pile is mixed at least twice during this period thus ensuring every part of the material is exposed to the higher temperature area at least once. A compost producer has to manage a precise protocol of the composting process in order to prove that the composts are hygienically harmless.

4.3 Conclusion

Few control measures are needed for the production of quality compost, as well as for selecting the adapted compost and its application strategy. The control measures described above are relatively simple to implement and are cheap. To successfully produce quality compost it is crucial to perform these tests regularly and carry them out carefully according to the protocol (sampling method, sample timing, performance of analysis). This is the key to the correct interpretation of these compost quality parameters in order to choose the right compost for the intended use and the optimal application strategy.

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