Lessons learned – how to produce quality compost

This paper summarises the basic requirements for sustainable composting of biogenous wastes.

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Abstract

Composting is a very important measure to close the nutrient cyclea and reduces waste amounts to be landfilled. Thus composting is an important part of sustainable waste management. Whole over the world – in industrialised as well as in low income countries – many composting plants show insufficient performance. In most cases when ABF-BOKU evaluated composting plants, the reason was missing knowledge of the fundamentals of the composting process. Composting is an aerobic process including a thermophylic stage. The involved microorganisms require water, oxygen and nutrients. Taking into account these main factors during the whole rotting process in most cases will lead to satisfying operation.

Introduction

Composting is an important component of municipal solid waste management systems in industrialised as well as in low income countries (Smidt et al., 2006). With a share of 50 % to more than 80 %, biogenous wastes are the main fraction in the wastes of low income countries. Because of their degradability, landfilled biogenous wastes cause in huge emissions contributing to greenhouse effect (methane) and pollution of groundwater, respectively.

Composting, on the one hand, reduces biogenous wastes disposed in landfills, which is a main topic in EU-legislation (European Landfill Directive (1999/31/EG)).

On the other hand, composting closes the nutrient and the organics cycle, which helps to save the soil functions by adding stable humus compounds as well as nutrients to agricultural land. The positive effect of compost is manifold (Binner et al., 2011). Enhancement of water holding capacity, porosity, aggregate stability, microbial life in soil, phytosanitary effects and many others are additional benefits to the fertilising effect (only the later may be replaced by mineral fertiliser).

Although high tech composting systems (bioreactors) were developed in industrialised countries, composting is possible by very simple, natural aerated open windrow systems too. The later can be operated by much lower investment and running costs, which is beneficial for low income countries. Requirement for the sustainable operation of composting plants is a detailed knowledge about the needs of the involved microorganisms. In the course of visiting composting plants in Africa, Asia and South America very often a lack in this knowledge was to be determined. Thus the idea of this paper is to provide the basic understanding of the requirements for composting for operators and workers of composting sites in low income countries.

Preliminary remark: Composting is an aerobic exothermic process (oxygen is essential) which is important for humification. Composting (except vermicomposting, which is not part of the paper) includes a period of

Key factors:

Requirements for production of high quality compost:

- source separate collection of biogenous waste fractions (to reduce pollutants)
- organic compounds should be well mixed from scarcely to easily available (important for sanitisation and humification)
- careful pretreatment of feedstock (adequate moisture, nutrients, structure, grain size)
- monitoring of the rotting process (organoleptic parameters like odour, colour and moisture, rotting temperature)
- frequent turning for keeping optimum rotting conditions (homogenisation, loosening, addition of water)

thermophylic milieu conditions which guarantees sanitisation (killing pathogens and weeds)!

Goals of Composting

Goals of composting are a fast but low loss degradation of biogenous wastes (biowaste, yardwaste, faeces, manure, …) and their conversion into **stable humic substances** with high germination effect. We want to keep organic matter as well as nutrients as much as possible within the final product (compost). Thus not mineralisation (degradation of organic compounds into mainly carbon dioxide, water and easy available/soluble nutrients) but humification (development of humic compounds and fixation of nutrients within the humus matrix) shall take place (Binner et al., 2011). Humification needs aerobic milieu; during anaerobic conditions no or only very low humification will take place (Binner and Tintner, 2006). Thus in the following, we will focus on aerobic degradation (composting).

Additional requirements for the final compost are proper sanitisation (human and plant pathogens as well as weeds have to be killed during the composting process) and a very strict limited amount of hazardous compounds (e.g. heavy metals) (BMLFUW, 2001).

To catch these goals the use of "clean" input materials, the preparation of adequate feedstock mixtures for the composting process and a careful processing are essential. Therefore detailed knowledge of the aerobic degradation process, the needs of the involved microorganisms (milieu conditions, oxygen, water and nutrient supply) and measures how to satisfy these needs is necessary.

Fundamentals of the composting/rotting process

Moisture is essential for biological degradation processes (Binner, 2016a). Microbes only can take up oxygen and nutrients when they are dissolved in water. If there is too less water available, biological degradation (aerobic as well as anaerobic) will stop. This effect (it is called "dry stabilisation") is reversible. At the moment when moisture is raised (e.g. by irrigation) biological processes start again – maybe with lower speed. Anyway, drying out of material leads to longer duration of the composting process.

Microbes need a balanced nutrient supply. Very important for proper processing is the C/N-ratio (= rates of available carbon and nitrogen). C/N of the feedstock material should be between (20) 25 and 35 (40). If it is too high (too much carbon), degradation will be inhibited because of shortage in nitrogen. If C/N-ratio is too low, microbes cannot incorporate all the available nitrogen – losses in nitrogen will occur. Nitrogen may be washed out by leachate (NH_4) or if pH-value increases to alkaline range, NH_3 may be set free into atmosphere. The latter not only leads to a loss in nitrogen, but also to emissions of bad odours respectively (Binner, 2016a).

As already mentioned above, composting is an aerobic process. Microbes use biogenous compounds, nutrients and oxygen for winning energy. During this process oxygen is consumed and carbon dioxide and water are released (Binner, 2016a). Approximately 60 % of the energy is set free as heat (Figure 1). To keep alive aerobic conditions, the consumed oxygen has to be replaced

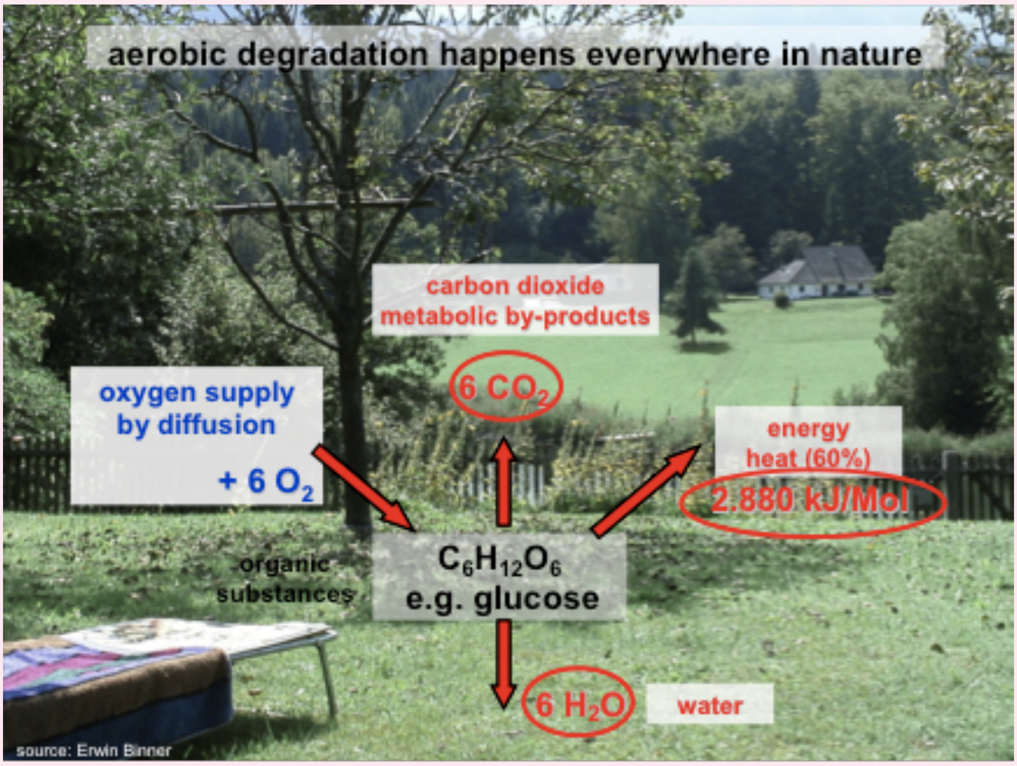

Figure 1. Principle of aerobic degradation – example glucose (source: Binner, 2016a)

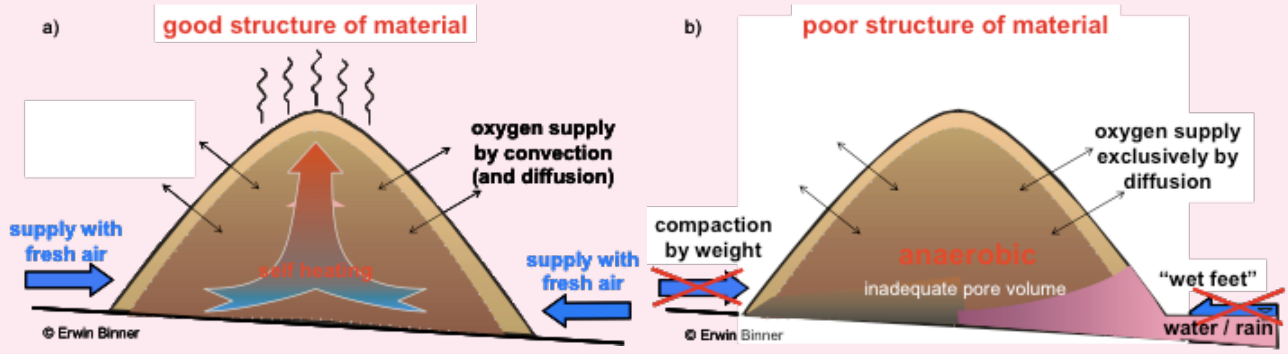

Figure 2. Principle of natural aeration of windrows; a) good structure and b) poor structure (source: Binner, 2016a)

immediately. Otherwise anaerobic conditions will occur. In the second case no humification will take place and methane (a strong greenhouse-gas) and bad odours (e.g. butyric acid, hydrogen sulphide) may be set free.

Oxygen supply by natural aeration

A simple and low cost solution to replace the consumed oxygen is shown in Figure 2a. After building the windrow, aerobic microbes immediately start the degradation process. Therefore no inoculation is necessary. All the needed microbes already exist in the biogenous wastes. Oxygen is taken from the pore-air. During the first hours the consumed oxygen is replaced by diffusion. Unfortunately diffusion is possible only via the surface; thus the efficiency is low. Fortunately, as already shown in Figure 1, by aerobic degradation heat is produced. Hot air (with low content of oxygen and high content of carbon dioxide) raises and leaves the windrow at the top. Thus a negative pressure takes place in the centre of the windrow. If the rotting material shows good structure (therefor careful pretreatment is necessary) this negative pressure sucks fresh, oxygen rich air from besides the windrow (blue arrows in Figure 2a) into the centre. By the chimney effect a convective flow of air takes place which fully automatically leads to sufficient air (oxygen) supply (Salhofer et al., 2014).

Very often structure of rotting material is inadequate. In order to get a large surface area for microbial attack, many operators of composting plants try to grind the feedstock to very small particle size. Another very often seen mistake is a too low amount of structure material (e.g. bush and tree trimmings). In many cases there is a lack of these materials (they are used for cooking and heating) or, because of hard degradability of woody materials, operators avoid addition of these compounds. Both mistakes reduce pore volume and structure stability.

But even if feedstock pretreatment was done well, pore volume may be inadequate. One possibility is compaction of the rotting material by degradation and the own weight. Another example is too much water (added by rainfall or irrigation). In this case almost all the pores are blocked by water and no free air pores are available for air flow. Thus collection and fast discharge of surplus water is essential, which is to be guaranteed by proper construction of the rotting surface (inclination of rotting surface, troughs).

In case of poor structure of rotting material (figure 2b) convective air flow is not possible. No fresh air is sucked into the windrow from the sides. Oxygen can enter the windrow only by diffusion, which, as already mentioned above, is insufficient (Salhofer et al., 2014).

If compaction by weight or high water content in the bottom layer of the windrow is the reason for low pore volume, turning the windrow (mixing, loosening) will help to reinstall adequate pore volume and convective flow respectively. If inadequate pretreatment of feedstock is the reason, turning will not help! Sufficient oxygen supply only by turning is impossible. Measurements of the pore air showed that during intensive degradation all the oxygen added during the turning event is consumed by microbes within 15 to 45 minutes.

Characteristic parameters during the rotting process

For better understanding of processing and getting knowledge how to monitor and influence the rotting process respectively, the different phases of rotting process have to be taken into account (Figure 3). The rotting process may be monitored via (more or less simple) measurement of temperature, ammonia and nitrate concentrations and pH-value. Another suitable parameter (which needs more sophisticated/expensive equipment) is the concentration of oxygen and/or carbon dioxide and methane in the pore air.

After building the windrows carboxylic acids are set free by hydrolyses. This leads to a decrease of pH-value during the first days of rotting process or already during collection/storage of biogenous wastes. Most aerobic microbes do not like low pH-values; thus degradation may be inhibited. Fortunately there are some specialised microbes, which tolerate low pH-values (fungi, few bacteria). They metabolise acids; pH-value increases (pink line in Figure 3) and conditions get optimal for aerobic microbes.

During the first stage - the **intensive** (degradation) **phase** - microbes use mainly easy available organic compounds. Because of very intensive degradation process (carbon

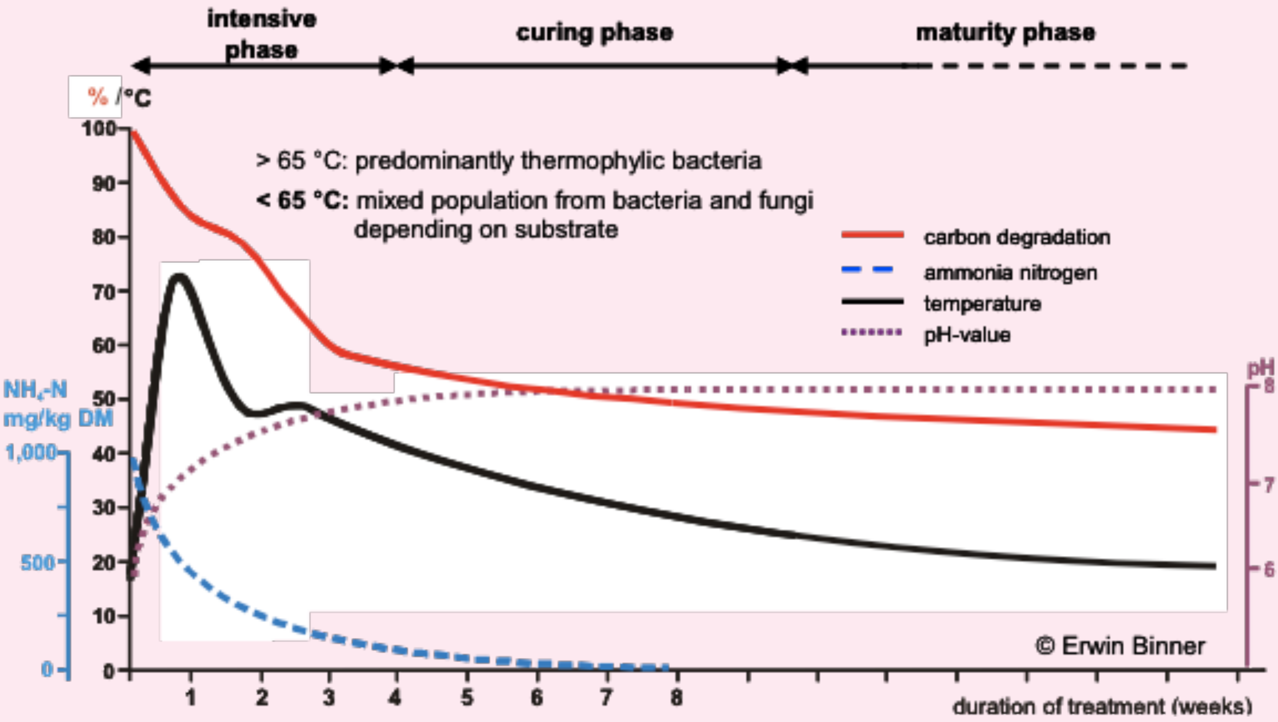

Figure 3. Characteristics of the rotting process (source: Binner 2016a)

content decreases quickly; see red line in Figure 3) temperatures increase very fast to a range of 60-70 °C (black line in figure 3). Thermophilic microbes replace the mesophilic ones. Intensive metabolism leads to very high oxygen consumption and carbon dioxide release. High molecular organic compounds are degraded into intermediate products, which may be very odorous (e.g. carboxylic acids). If oxygen supply is sufficient, these metabolic by-products are degraded immediately. Also nutrients (e.g. NH_4) are dissolved and may be set free by leachate (blue line in Figure 3). After easy available compounds already are consumed, temperatures decrease (speed of degradation gets slower) and a change in microbial population takes place, shown very often by a slight second temperature peak (Binner, 2016a).

Curing phase is defined by temperatures lower than 40 °C (BMLFUW, 2005). Again mesophilic microbes dominate the degradation process. At this stage normally pH-value has increased higher 7 and ammonium content has decreased. Carbon degradation rates get lower; also oxygen consumption decreases (turning intervals now may be extended).

Whether **maturity phase** is necessary or not depends on compost utilisation. For use in agriculture in many cases compost can be used already after curing stage. For vegetables, gardening, pot flowers etc. further maturation is necessary. By this, further stabilisation and increase of plant compatibility happens (Binner, 2016a). The total duration of the composting process depends on the anticipated use of the compost as well as on the properties of input materials and rotting technique. Mainly the intensive phase may be enhanced by technical measures. In case of forced aeration, the intensive stage may be finished within 2 to 4 weeks. In natural aerated systems this will last 4 to 8 weeks. For curing stage in both cases another 6-10 weeks by natural aerated windrows with reduced turning frequency will be necessary.

Enhancement of degradation by forced aeration includes a very often not considered danger! Numerous operators try to shorten rotting duration as much as possible. This enhances mineralisation and a strong decrease of organic carbon content. By mineralisation all the metabolic products – which are essential for humification – are transferred into carbon dioxide and water. Thus they are not available for further humification (Binner et al., 2011). The result of this process is a well stabilised but carbon (humus) poor compost. As already mentioned above, carbon should be kept in the compost (total carbon loss < 50 %).

Measures to enhance rotting process and compost quality

Input Materials

Properties of input materials are essential for rotting process and compost quality. Organic compounds should be well mixed from scarcely to easily available. A mixture of manifold materials is beneficial for humification (Binner et al., 2011).

Figure 4. Device for particle size reduction

Easy available biogenous material also is necessary for sanitisation (Binner, 2016a). Only a certain amount of easy degradable compounds allows temperatures > 55 °C which are required to kill pathogens and weeds. Thus for composting of faeces (by digestion in human stomach faeces are already pre-stabilised) it makes sense to add some biowastes from kitchen or market etc.

Mineral compounds are not degradable. All the heavy metals in the input material will remain in the final compost (only a very small share may be washed out by leachate). Thus again, high input quality is important for later compost quality. Source separate collection ("biobin") of the biogenous fractions of waste is essential. A mechanical separation of mineral compounds from mixed waste after delivery to the composting plant cannot reach adequate quality - even if done by manual sorting. In this context also separate collection of hazardous wastes from households (batteries, fluorescent tubes, medicines etc.) makes sense and helps to reduce pollutants in compost.

Input materials with different properties should be stored separately. This gives the chance to dispense feedstock material by mixing proper shares of the different types.

Pretreatment of feedstock

Proper pretreatment of feedstock (= material mixture for starting the rotting process) is one of the most important items for composting. Many different demands on the feedstock have to be considered.

As already mentioned, microbes need a **C/N-ratio** between (20) 25 and 35 (40). It is well known that wastes from food preparation, residues from meals, market waste, grass and river-plants show high nitrogen content and low C/N-ratio, respectively. Also sewage sludge and faeces show low C/N-ratios. Carbon rich materials (high C/N-ratio) are trimmings from bushes and trees, straw, saw dust, untreated wood and bark and even overflow from final sieving of compost. A rough estimation of the different input materials by experience allows to install a proper C/N-ratio (it is not necessary to analyse all input materials prior mixing). Important in this context is the availability of carbon and nitrogen. Thus only adding large wooden parts will not fit. Woody materials have to be grinded to increase the surface for the attack of microbes (Binner et al., 2011).

On the other hand we learned that **pore volume** (structure) is essential for the aeration of the windrow by convective flow (Binner et al., 2015). This fact argues against reduction of particle size (Figure 4). Thus we have to find a compromise between large surface on the one hand and structure and structure stability during the whole rotting process on the other hand. Reduction of particle-size has to be done carefully. Not cutting but crushing/fraying should be used; by this also bigger particles show large surface. Feedstock for natural aerated windrows needs a particle-size distribution from saw dust size up to wood parts of 20 cm length.

Straw enhances **C/N-ratio** but increases the pore volume only for a short period. The structure stability of straw is too low. If only straw is available, the dimensions of windrows have to be reduced. But attention! Too small dimensions of windrows enhance cooling effects and sanitisation may fail.

Figure 5. Composting of paper-mill sludge – example for too less free air space.

Figure 6. a) Windrows covered by geo textile b) example for a rotting platform roofed by shed.

The share of structure rich material depends on the properties of the low pore wastes (easy degradable very wet fractions need higher amount than scarcely degradable and dry fractions), aeration technique (forced aeration needs less structure than convective aeration) and the dimensions of the windrows (the larger the dimensions the more structure material is needed). In natural aerated windrows the volume of air filled pores (free air space = FAS) should be approximately 50 vol% (BMLFUW, 2005; Binner et al., 2002). Figure 5 shows a site where paper-mill sludge is composted. Obvious this feedstock is much too fine! To enhance aeration, tubes were installed through which air can be pressed in by force. This only would fit, if aeration is done permanently (15-45 minutes after stopping aeration the oxygen already will be consumed by microbes)!

Another compromise is needed for **moisture content**. As already mentioned water is essential for microbial degradation processes. On the other hand water also may block the pores, which decreases convective flow! It is impossible to define the theoretical optimum water content, because the optimum depends on the feedstock properties (water holding capacity, structure) and the rotting technique (aeration, dimensions of windrows). Thus it may differ in a wide range. In most cases the optimum water content is in the range of 50-60 %WM, but local conditions always have to be kept in mind (Binner, 2016a). If there is doubt about optimum moisture content it is better to add too less water than to add too much. In first case some more water has to be added during turning events. In the second case high leachate amount will be set free and material may get anaerobic.

Construction of rotting platform and windrows

During intensive degradation phase windrows have to be placed on a sealed surface, independent whether the rotting platform is covered by a roof or not (BMLFUW, 2005). During degradation water is produced (see Figure 1); the leachate runoff has to be collected and treated or reused for moistening. Therefor an inclination of the rotting surface, proper troughs and a leachate storage basin are necessary (Linzner et al., 2007). For curing and maturation pounded (not sealed) surface fits (during these rotting stages only a low amount of water will be set free).

Depending on the climate situation (precipitation, sunshine hours), the windrows have to be **covered** by geo textiles (Figure 6a) or the rotting platform has to be **roofed** by shed (Figure 6b) (Salhofer et al., 2015). It is not necessary to situate the rotting platform in a hall (except odour emissions are a problem). On the one hand rainfall water entering the windrows has to be minimised. Moistening is to be done carefully by estimated irrigation. On the other hand roofing or covering reduces evaporation from the surface. Thus a better control of the rotting process is possible. If covering is done it has to be considered that aeration will not be hindered. Thus special geo textiles (waterproof but permeable for air and vapour) have to be used. **Never use plastic foils** (Binner, 2014); they are impermeable for air too!

A sometimes made mistake is shown in Figure 7a. So called "pit composting" (Binner, 2015) is not really composting (= aerobic process) because it is not possible to keep alive aerobic conditions by this technique (except forced aeration is installed). In a pit convective flow is prevented – no fresh air from besides can be sucked into the windrow. Milieu will change to anaerobic conditions immediately. Methane and odour emissions will occur, no humification will take place and nutrients will keep easy soluble. **Thus composting always has to be done above surface!**

Appropriate types of windrows for natural aeration are conic windrows (Figure 7b) and triangular or trapezoidal windrows respectively (Figure 6a). Table piles – because of the large distance from surface to the centre – need forced aeration from the bottom; for natural aeration table piles are not suitable.

Figure 7. a) "Pit composting" – adequate aeration is impossible; b) Conic windrow

Correct dimensioning of windrows is a very important topic too (Binner, 2015). Adequate aeration by convective flow always has to be kept in mind! Therefor height of windrows depends on the pre-treatment of the feedstock (grainsize, water content, bulk density) and the rotting stage (Binner, 2015). Smaller grainsize, higher moisture or bulk density and earlier rotting stage (intensive phase) require lower height of windrows. On the other hand too small dimensions enhance temperature losses from windrows. In this case thermophylic stage may be too short for sanitisation and/or proper degradation. This especially may be a problem when using conic windrows. In case of natural aerated windrows in most cases a height between 1.1 and 1.5 m fits. Figure 8a shows a windrow which is obviously too high related to grain size and structure respectively. Figure 8b shows proper dimensions of the windrow.

Rotting process

<u>Monitoring the rotting process</u>

The rotting process has to be **monitored** in order to recognise inadequate conditions and to intervene respectively.

Simplest method for monitoring is **optic and organoleptic control**. Digging some decimetres into the material, looking to its colour (black colour is a sign for anaerobic conditions), touching for proofing moisture or crumb stability and sniffing at a sample (bad odours are a sign for unfavourable conditions, smell like in the forest is a sign for a nearly finished process) give first information about rotting conditions.

Moisture content may be monitored by analysing water content (by drying at 105 °C) or – much better – by fist test (Binner, 2016b). As already shown in chapter "Pretreatment of feedstock", the optimum water content depends on feedstock properties. It also changes during the rotting process (during intensive phase higher moisture is needed than during curing and maturation). Thus the knowledge of the exact actual water content (which analyses needs minimum 24 hours) in most cases does not allow to predict the actual optimum water content. Fist test immediately gives the needed information. For fist test take some material into your hand and press it carefully by clenching your fist. If water is running out moisture is too high (Figure 9a). If after opening the fist material falls completely apart and the hand still is "clean", moisture is too low (Figure 9b). Adequate moisture is shown by lumping material in which still pores can be seen and a dirty hand (Figures 9c and 9d).

Figure 8. a) Windrow, too high related to feedstock properties b) windrow according to feedstock properties.

Figure 9. Fist test for evaluation or moisture content during composting a) too wet b) too dry c) and d) adequate moisture.

In case, moisture is recognised as too low, water addition is necessary to avoid dry-stabilisation. Water addition has to be done very carefully! If too much water is added, almost all pores will be blocked by water which will inhibit transport of oxygen. Water addition by irrigation or by water cans onto the surface only moistens the upper layers of the windrow. Thus after water addition in every case the windrow has to be turned for mixing and homogenising water content.

In case water content is too high, it is hardly possible to reduce it. Some evaporation happens during turning windrows. The amount of evaporation depends on rotting temperature (larger during intensive phase than during curing and maturation). Thus turning may help to create proper conditions again. But in most cases (of too high moisture) material has to be mixed with new feedstock and the process has to be started once more.

In every case **rotting temperatures** are to be monitored by lances with length of 50-100 cm (figure 10a) (Linzner et al., 2007). Measuring points are minimum 3 per windrow, each in the centre, 2/3 of height distance from the bottom (mostly in this height there is the temperature maximum) or in both thirds (Figure 10b). Temperatures give information about rotting stage (see Figure 3) and by the time/temperature regime sanitisation can be guaranteed. The higher the observed temperatures the shorter the duration necessary for killing pathogens and weeds. Austrian regulations (BMLFUW, 2001; BMLFUW, 2005) require either 2x3 days with temperatures > 65 °C (with one turning event after 3 days) or 10 days with > 55 °C (with 3 turning events in between). An example for proper temperature monitoring by the 55 °C-method is shown in Figure 11.

Very useful information is given by the composition of the pore gas: oxygen (O_2), carbon dioxide (CO_2) and methane (CH_4) allow to evaluate oxygen supply. By lances (at same points as temperature) pore air is sucked out of the windrow and measured to its composition (Binner et al., 2016b). Relatively cheap equipment (approx. 500 €) is available for measuring oxygen content. More sophisticated (and expensive) equipment is available for measurement of all the 3 gaseous components at once (the price for landfill gas measurement equipment as shown in Figure 10 is approx. 4‘500 €).

During aerobic degradation 6 molecules of oxygen are transferred to 6 molecules of carbon dioxide. This is an equivalent volume. Thus by measurement of either oxygen or carbon dioxide, monitoring is possible (the

Figure 10. a) Measurement of rotting temperature and composition of pore gas b) location of measurement points in the windrow.

sum of O_2 + CO_2 under strict aerobic conditions always is around 21 vol.%) (Binner et al., 2015).

It is aimed to have not less than 10 vol.% O_2 content in the pore air (this is equivalent to approx. 11 vol.% CO_2). During intensive degradation phase – because of the very high consumption of oxygen by microbes – this target not always can be reached. When oxygen drops below 5 vol.% intervention (turning, enhancing forced aeration) is necessary.

If both compounds (O_2 and CO_2) are monitored more exact evaluation of milieu conditions is possible. Whenever the sum of O_2 + CO_2 is higher than 21 vol.%, this is a sign for already starting anaerobic degradation although no methane is detectable. Sums of O_2 + CO_2 up to maximum 25 vol.% may be tolerated; otherwise intervention is necessary (Binner et al., 2002). By turning events the oxygen supply can be enhanced (loosening, increase of pore volume).

Ammonium nitrogen (NH_4-N) and pH-value show characteristic development (see Figure 3). Therefore both parameters can be used for monitoring of the rotting process. The pH-value mainly is influenced by waste properties. Long storage of kitchen and market wastes (in waste bins at place of origin or even after delivery in the composting plant) leads to a decrease of pH-value (Binner and Kitzberger, 2003). As already mentioned, low pH-value of the feedstock causes in stagnation of aerobic degradation (a so called lag-phase occurs) (Binner et al., 2002). In order to avoid and reduce long lag-phases respectively short collection intervals and immediate pretreatment of materials after delivery will help. If pH-value still is too low, a carefully addition of ash (from wood incineration) or lime may help. But attention! If too much ash or lime is added, the pH-value may become alkaline, which also inhibits microbes. Investigations in the ABF-BOKU laboratory showed that in one case 0.2 % of lime addition were too less, 0.4 % showed optimum results but already 0.6 % were too much (Binner and Kitzberger., 2003)! Thus it is only a very limited share which will lead to positive effects. This share differs from feedstock to feedstock!

Ammonium is influenced by input materials and rotting conditions. Easy degradable compounds containing high nitrogen content will cause in high ammonium concentrations in the rotting material. Thus for ammonium concentrations also C/N-ratio (pretreatment of feedstock) is very important. In case of sufficient oxygen supply ammonium (NH_4) will be oxidised to nitrate (NO_3) and/or incorporated into microbial biomass and into humic compounds respectively. Thus ammonium concentrations decrease within a few weeks (Binner, 2016b). If pH-value is in alkaline range – this is another danger when adding lime or ash – ammonium (NH_4) may be transferred into ammoniac (NH_3). Ammoniac is a very odorous gas, which leaves the windrow within the waste air. This will lead on the one hand to problems with the neighbourhood and on the other hand to nitrogen losses (lower compost quality).

Possibilities for interventions

Whenever the monitored parameters show unsatisfying results, intervention is necessary. Type of intervention depends on the reason for inadequate conditions.

Moisture content can be influenced by careful irrigation (if moisture is too low), addition of structure material (if feedstock moisture is too high) and protection measures against rainfall by covering windrows or roofing the rotting area (if too high moisture is caused by precipitation). In every case after water addition the windrow is to be turned (homogenised). Otherwise added water will reach only the outer zones of the windrow (Binner, 2016b).

If **temperatures** do not increase after building windrows, acidification (low pH-value), inadequate moisture or missing structure (lack in oxygen) may be the reason (Binner and Kitzberger, 2003). Thus adding ash (in case of low pH-value), some fresh structure material or water and turning may help. If during rotting process temperatures are too high or too low (referred to the rotting stage and black line in figure 3 respectively) in most cases turning (eventually plus addition of water) will fit. Sometimes changing windrow dimensions (smaller if temperatures are too high and larger if

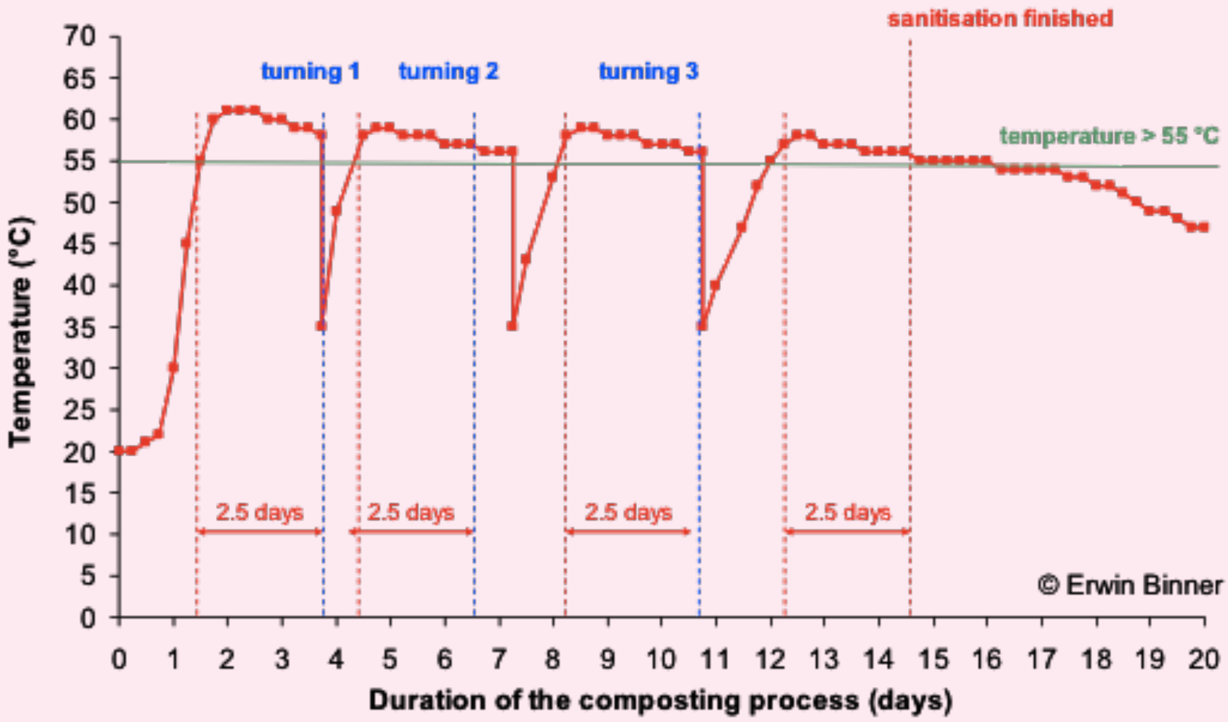

Figure 11. Time/temperature regime for guaranteed sanitisation - according to Austrian Regulations (Binner, 2016b)

Figure 12. Turning of windrows a) manual b) front-end loader c) turning machine d) detail of a self-powered turning machine.

Figure 13. Unfavourable operation

temperatures are too low) may be necessary.
In case of inhomogeneity (very different results of measurement in the different measuring points) or inadequate **pore-air composition** (<<O_2, >>CO_2, CH_4), turning (loosening) enhances rotting conditions. Turning may be done manually by shovel (Figure 12a), by front end loader (Figure 12b) or by special turning machines (Figure 12c). Turning by shovel is effective, but needs a lot of employees. Thus this method fits only for small composting plants. Because of missing mixing effect turning by front end loader is not really effective. The operator needs very high skilfulness to get some mixing effect too. That is why in almost all large composting plants, turning machines are in operation (Salhofer et al., 2014). Windrow turner may be pulled by a tractor (Figure 12c) or self-powered (Figure 12d). Machines moved by tractor may be self-constructed; therefore they are cheaper than self-powered machines. Turning machines have a horizontally rotating cylinder, containing special baffle plates (Figure 12d). By the rotating cylinder the rotting material is thrown up, loosened and dropped down to a triangular windrow again. The turning has to be done as gentle as possible (low reduction of structure). Very important is the proper construction of the baffle plates, otherwise it will not be possible to build up a perfect triangular windrow.

If the deficit is caused by inadequate pretreatment or too high moisture (too less pore volume/structure) again addition of further structure material and/or changing windrow dimensions will help. Sometimes operation of windrows is done in a wrong way. For example, never step on the windrows (Figure 13) – this leads to compaction and loss in pore volume. In all these cases verification and adaption of pretreatment-technology will make sense for future operation of the composting plant.

If after longer rotting period (more than 4 weeks) still **low pH-value or high ammonium** concentration is recognised, something of the rotting process runs very wrong (Figure 3). In this case investigations about the reason(s) are necessary. It may be necessary to change feedstock preparation (shares of different wastes, grain size) and/or rotting technique (dimension of windrow, turning frequency, moistening).

Compost finishing

Last step in compost production is the final treatment (Linzner et al., 2007). In most cases this is done by sieving, which may be done manually (Figure 14a) or by sieving machines. Sometimes also separation of impurities has to be done (air separation, hard material separation). A simple self constructed drum sieve is shown in Figure 14b. For better sieving performance the material should not be too wet (high moisture causes in lower amount of compost and higher amount of overflow). On the other hand, compost should not be dried out because after application this would lead to less positive effects to the soil properties (lower water holding capacity, lower crumb structure, etc.). The grain size depends on the planned use of compost and will vary between 6-10 mm (flower pots, gardening) via 15-25 mm (agriculture) up to 35-40 mm (biofilter). Depending on customer request, compost may be sold in bulk or packed. The overflow or sieving process may be added as structure material to the next batch of feedstock.

Conclusion

The basis for sustainable operation of composting plants is a detailed knowledge about the needs of the involved microorganisms. Composting is an aerobic process, including a thermophilic stage. Goal is a fast but low loss degradation of biogenous wastes (biowaste, yardwaste, faeces, manure, etc.) and their conversion into **stable humic substances** with high germination effect.

Compost quality (humic compounds, nutrients and pollutants) mainly is influenced by feedstock materials (nutrients, pollutants) but also by processing (humification, nutrient losses, sanitisation). Thus source separate collection of biogenous wastes is essential.

Another key factor for proper composting is **feedstock pretreatment.** Moisture, nutrient ratio (C/N-ratio) and satisfying oxygen supply are essential for the aerobic rotting process. For oxygen supply pore volume and structure stability are important. A certain share of well prepared (not too small particle size!) structure rich material (tree and bush trimmings) is required. According to structure properties adequate **rotting technique** has to be chosen (dimensions of windrows, type of aeration, turning frequency).

Monitoring of rotting process may be done by simple organoleptic measures (moisture, colour, odour) and additional control of rotting temperature (guarantee of sanitisation), composition of pore gas (oxygen, carbon dioxide, methane), pH-value or ammonium content. In case monitoring shows sub-optimal conditions,

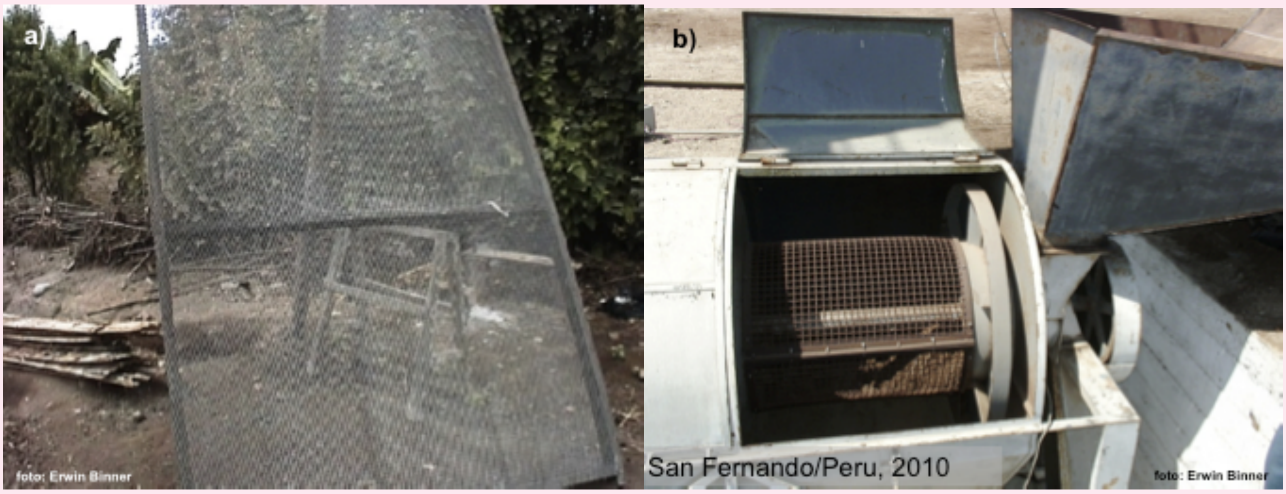

Figure 14. Final Treatment by sieving: a) manual; b) sieving machine

adequate intervention by turning (loosening for enhancement of pore volume, homogenisation), moistening (calculated irrigation) or even changes in rotting technique (reducing size of windrows, adding structure materials) is necessary.

References

BMLFUW (2001): Kompostverordnung. Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über Qualitätsanforderungen an Komposte aus Abfällen. BGBl. II Nr. 292/2001, Austria [in German].

BMLFUW (2005): Stand der Technik der Kompostierung. Richtlinie des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft Vienna/Austria; 10.02.2005 [in German].

EG (1999): European Landfill Directive (1999/31/EG).

Binner, E., Grassinger, D., Humer, M. (2002): Composting Conditions Preventing the Development of Odorous Compounds. In: Microbiology and Composting, Springer-Verlag Wien New York, pp. 551-560.

Binner, E. and Kitzberger, K. (2003): Conditions/Parameters Characterizing the Composting Process. In: Cossu R., Diaz L.F., Stegmann R. (Eds.): Sardinia 2003, Ninth International Waste Management and Landfill Symposium, Vol. I (6-10 October 2003), Margherita di Pula - Cagliari, Sardinia, Italy.

Smidt, E., Meissl, K., Binner, E., Huber-Humer, M. (2006): Source separation and composting as part of an integrated waste management and economics of biowaste collection and treatment. In: European Compost Network (ECN, Eds.): Biowaste - Compost – Soil, Conference material, 24-26 October 2006, St.Pölten, Austria.

Binner, E., Tintner, J. (2006): Impact of Feedstock and Rotting Process on Compost Quality. In: Kraft, E., Bidlingmaier, W., de Bertoldi, M., Diaz, L.F., Barth, J. (Eds.): Proceedings ORBIT 2006. Biological Waste Management. From Local to Global - Part 2 „Composting - Quality, Application and Benefit, Life Cycle Analysis, Sludge and Soil“, 13-15 September 2006, Weimar, Germany, pp. 409-416 (ISBN 3-935974-09-4).

Binner, E., Smidt, E., Tintner, J., Böhm, K., Lechner, P. (2011): How to enhance humification during composting of separately collected biowaste: impact of feedstock and processing. Waste Management & Research 29(11), 1153-1163.

Binner, E. (2014): Dimensionamiento de plantas de compostaje. Presentation, Curso Internacional “Fundamentos y Diseño de Plantas de Compostaje”, 24-26 April 2014, Universidad Agraria La Molina, Lima, Perú [in Spanish].

Binner, E. (2015): Incineration (MWSI) and Composting. Presentation, Curso doctorado „Manejo de Residuos Sólidos“, 9-14 September 2013, Universidad Nacional Agraria La Molina, Escuela Postgrado, Lima, Perú.

Binner, E., Hrad, M., Kraus, G., Huber-Humer, M. (2015): Einfluß unterschiedlicher Strukturmaterial¬zugabe auf die Emissionssituation und Kompostqualität der Kompostierungsanlage Lobau. Final project report, BOKU University, Vienna. Austria, 93p [in German].

Binner E. (2016a): Der Rotteprozeß. Course material, ÖWAV Kompostkurs, 7-9 March 2016, Linz, Austria [in German].

Binner E. (2016b): Prozeßführung und Meßtechnische Begleitung. Course material, ÖWAV Kompostkurs, 7-9 March 2016, Linz, Austria [in German].

Linzner, R., Binner, E., Mentler, A., Smidt, E., Salhofer, S., Souma, M. (2007): LPCC-Guinée: Recirculation of local organic waste in urban and rural agriculture – the impact on soil functions in Guinea / West Africa. Final project report, Commission for Development Studies, Austrian Academy of Sciences, Vienna, Austria, http://www.kef-research.at/fileadmin/media/stories/downloads/Projektberichte/P139_Endbericht_Guinea.pdf (last access: 25 April 2016).

Salhofer, S., Binner, E., Ramusch, R., Spitzbart, M. Herbeck, E., Magashi, A. (2014): Strategic Options for Waste Management in Zanzibar. Final report for UNIDO, Vienna, Austria.

Salhofer, S., Binner, E., Ramusch, R., Spitzbart, M. (2015): Upgrade of a Waste Management Facility in Zanzibar - Module 1. Final report for UNIDO, Vienna, Austria.

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