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Composting

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Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation“ bereit zu stellen. „sustainable“ also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation“ interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erschient vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

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Publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

Cover Photo / ***Titelbild***

Kolfe Keranyo Composting Site, Addis Ababa; Erwin Binner

Editorial

Besides sanitation, solid waste management plays an important role in improving the hygienic conditions in cities. There are several strong links between sanitation and solid waste management. In sanitation systems without sewers, urine, faecal matter and faecal sludge have to be collected from the single households such as solid waste. Faecal matter as well as sludge from wastewater treatment plants can be treated by composting to produce fertiliser.

Issue 26 of Sustainable Sanitation Practice (SSP) is thus devoted to „Composting". The contributions for this issue have been collected with the help of Erwin Binner from the Institute of Waste Management at the University of Natural Resources and Life Sciences Vienna (BOKU). Selected aspects of „Composing" are described in the following four contributions:

- Erwin Binner describes the fundamentals of composting and the requirements for producing good compost in the first paper.
- In the second paper, the composting facility for separately collected biowaste of the City of Vienna is described by Wojciech Rogalski.
- The design of a composting plant in Greece for about 77'000 inhabitants is shown in the third paper by Christina Chroni et al.
- The last paper by Christoph Engelhardt and colleagues describes field trials with compost from wastewater treatment plants in China.

In Issue 27 (July 2016) we will present the results of „Sustainable Sanitaion Kitgum" project, a project that started in November 2012 and will end in May 2016. The project was carried out in Kitgum, Uganda, and funded by the Austrian Development Agency.

Please feel free to suggest further topics for issues of the journal to the SSP editorial office (ssp@ecosan.at). Also, we would like to invite you to contact the editorial office if you volunteer to act as a reviewer.

SSP is available online from the journal homepage at the EcoSan Club website (www.ecosan.at/SSP) for free. We also invite you to visit SSP and EcoSan Club on facebook (www.facebook.com/SustainableSanitationPractice and www.facebook.com/EcoSanClubAustria, respectively).

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/SSP)

Content

Lessons learned – how to produce quality compost

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

Author: Erwin Binner

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

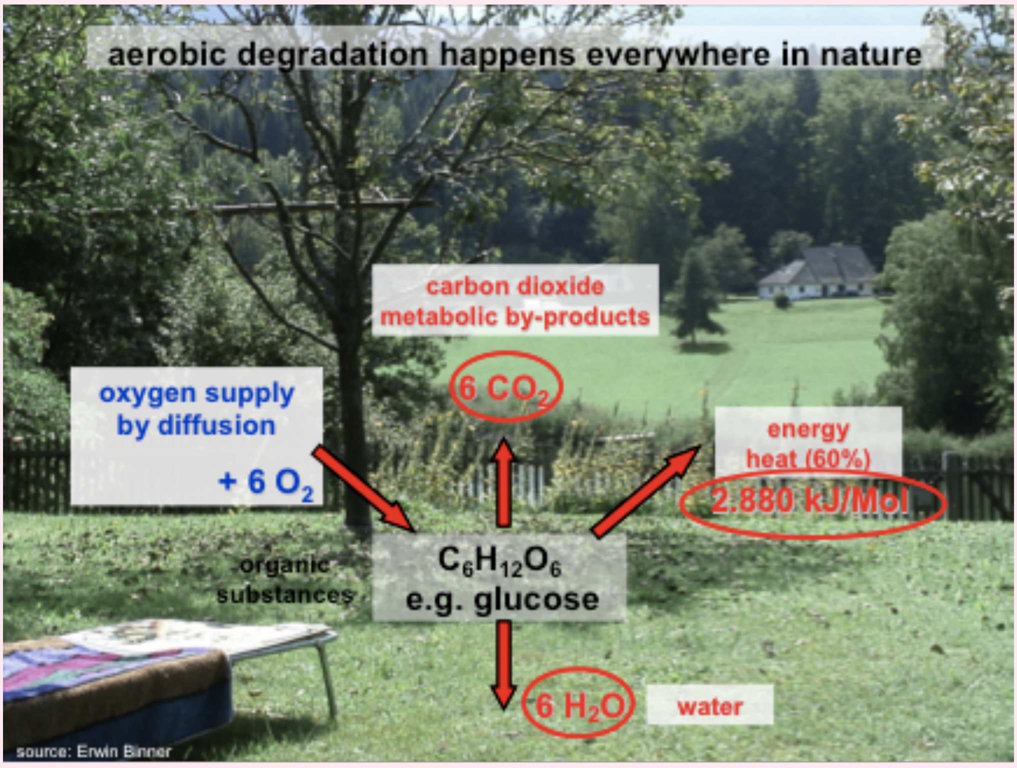

Figure 1. Principle of aerobic degradation – example glucose (source: Binner, 2016a)

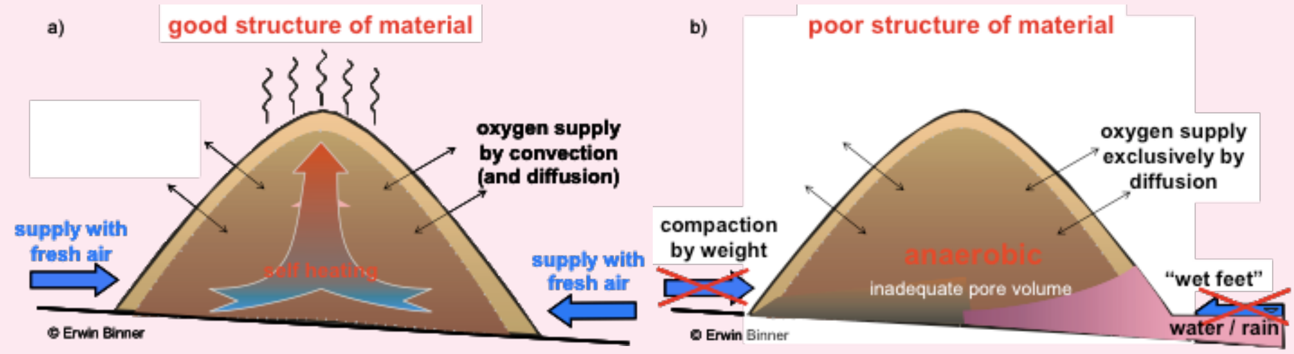

Figure 2. Principle of natural aeration of windrows; a) good structure and b) poor structure (source: Binner, 2016a)

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

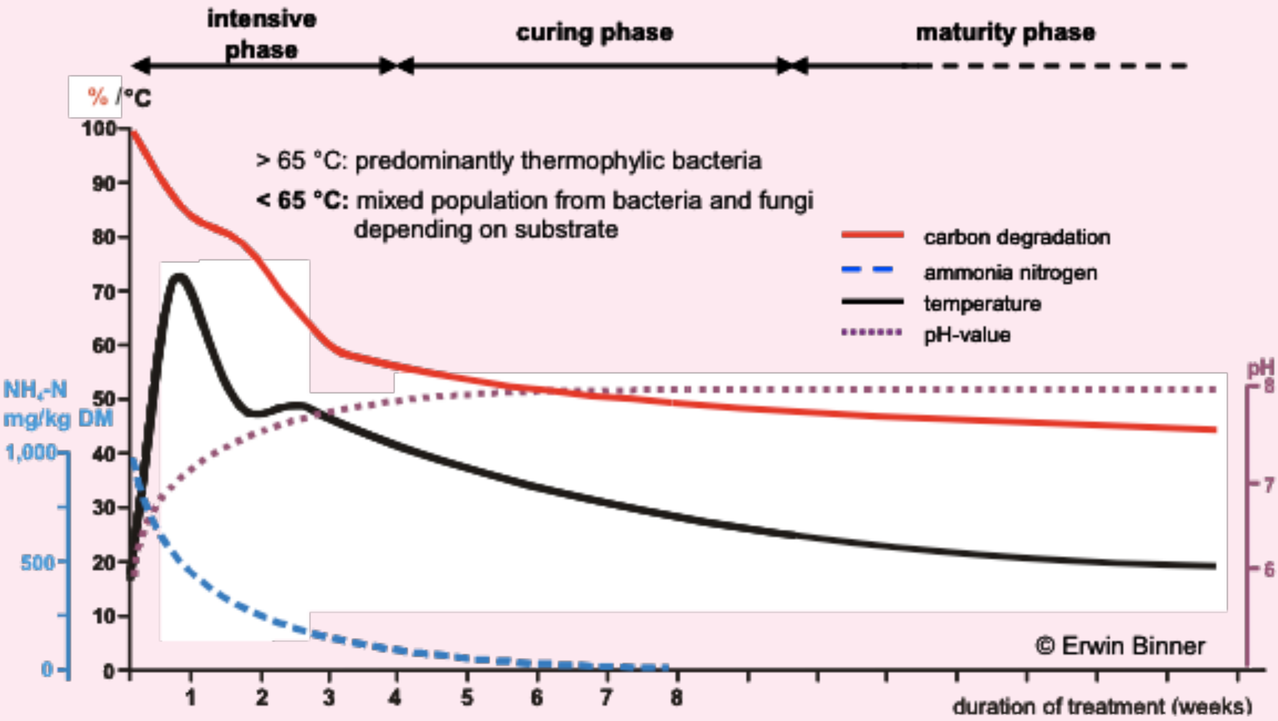

Figure 3. Characteristics of the rotting process (source: Binner 2016a)

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

Monitoring the rotting process

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

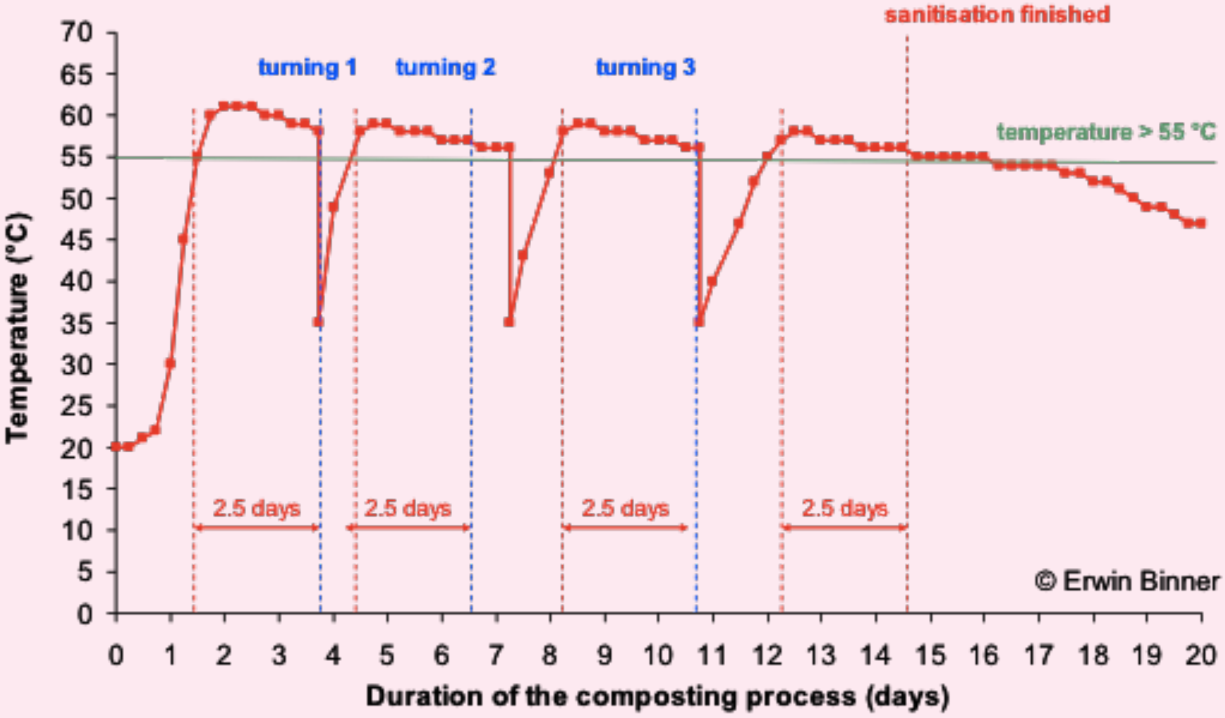

Figure 11. Time/temperature regime for guaranteed sanitisation - according to Austrian Regulations (Binner, 2016b)

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,

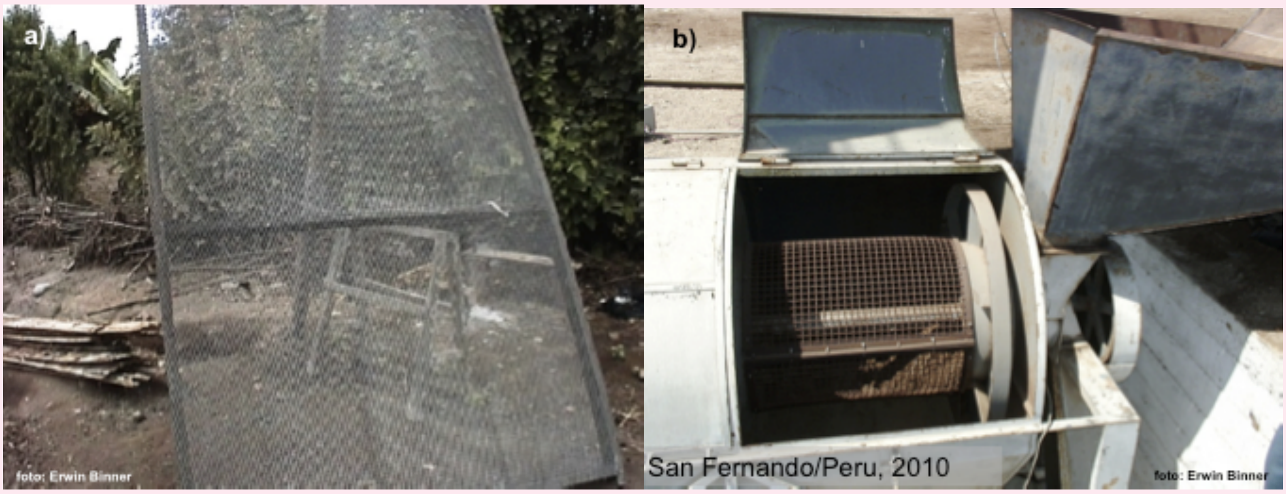

Figure 14. Final Treatment by sieving: a) manual; b) sieving machine

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.

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Composting of separately collected biowaste in Vienna - an example of BAT

The paper describes composting facility for separately collected biowaste of the city of Vienna.

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Abstract

In Vienna, the Municipal Department (MA) 48 (Waste Management) is responsible for collection, treatment and disposal of solid waste. Separate collection of biowaste was introduced in 1986. This is a precondition to product high-quality compost with low concentrations of contaminants. The paper described the composting plant Vienna Lobau that is designed for producing 40‘000 tons high-quality compost each year. The compost is used in municipality-owned farms and gardens, is given away for private use for free, and is sold to farmers in the neighbouring districts.

History of organic waste management in Vienna

Organic waste has accompanied humans from time immemorial. In the course of evolution, a natural eco-system developed which ensured environmentally compatible deposit, degradation and recycling of all ancillary and final products of biological-chemical activities. This eco-system guaranteed smooth preparation of general metabolic products, a process which initially encompassed humans as well. It was only humankind‘s cultural and economic development which made people aware of the production of undesirable substances.

Right into the 1960s, the household waste of a city included more than 60% of organic substances (today about 30%). At that time, many communities introduced composting as a technical method of waste disposal. Vienna similarly had a composting facility, which operated up to 1981. Over time, the (residual waste) compost produced by it, however, deteriorated in its quality until it became totally useless.

A new sorting plant completed in 1981 and run by the company Rinter AG was intended, i.a., to improve the quality of the organic waste fraction, but even complex technical measures employed by it could not adequately separate mixed waste.

The time was ripe to take another step forward: in 1986, a trial was launched for the separate collection of organic waste.

From its very start till today (2016), separate collection of such substances was considered as a part of organic waste recycling management. The idea of recycling was not new in itself. What was new was the realisation that each station of such a recycling process needs to be taken into account equally, from purchasing to separate collection, composting, applications in farming up to food production and marketing.

Public awareness of the effects of consumption

For the Municipality of Vienna, the chief task is to create public awareness for the effects of the generation of great amounts of waste on our society. To show that the throw-away society is damaging to the environment and thus has no future is done, by public awareness-raising campaigns.

Key messages:

The composting plant Vienna Lobau

- is operated by the City of Vienna‘s Municipal Department MA48 (Waste Management),
- is designed to treat more than 150‘000 tons separately collected biowaste per year, and
- produces 40‘000 tons high-quality compost per year.

Separate waste collection

A first bio container („Biotonne“) trial was started in 1986 based on the necessity of a separate organic waste collection to produce high-quality compost. Initially introduced on a test basis, the collection system was systematically developed. The experiences obtained in the process provided the main framework and targets of today‘s concept, which includes (a.o.):

- Only green-waste (from garden and household incl. kitchen) is being collected separately
- The quality of the material collected in the suburban areas is incomparably better than that obtained in central districts.
- The system best suited for the City of Vienna is a mixture of delivery and pick-up systems. The next “Biotonne” site should be located either within the property or in the immediate vicinity, if possible at a distance of not more than 50 metres.
- Containers are emptied at least once a week, even though tests are carried out to extend the intervals during the winter months. These tests have so far been generally successful.
- The separate collection of bio waste is free of charge; a system of fees based on „causation“ cannot be justified in a large city.
- The scheme must be accompanied by public relation activities, ensuring that the image of organic waste remains positive, e.g. by granting equal standing to separate organic waste collection and the compost heaps in private gardens.
- The guidelines for separate organic waste collection need to be precise and consistent; recommendations on substances to be collected must be restrictive. Meat, bones, cooked or liquid food, and remains of dairy products must be excluded from collection.
- In Vienna, private composting is not an equal and reliable alternative to the “Biotonne”, but is nevertheless to be promoted in private (common) gardens, provided that the initiative comes from the citizens.

Figure 1. Closed Loop of Bio waste Management in the City of Vienna.

Waste composition

In Vienna, organic waste is either collected in the “Biotonne” system or the waste depots or supplied by private companies. There is none collection of kitchen waste from private households in Vienna.

The composition of waste has changed in recent years. In terms of its constitution, waste from waste depots and private deliveries has more structural material; some 40-50 % of the “Biotonne” waste consists of partly structure-building components. The waste is always exclusively vegetable in origin. Other organic waste, such as meat waste, bones, liquid or cooked food scraps must not be put into a “Biotonne”. Microbiologically degradable sources of carbon and nitrogen are available at a balanced ratio. A C/N ratio of (20) 25 - 35 (40) / 1 can be assumed as a target ratio for the feedstock mixture.

Microorganisms are able to take up nutrients as well as oxygen in soluble form only. A sufficient degree of humidity, particularly during the initial and intensive/active rotting stage, is thus indispensable. The optimum degree of humidity decreases in the course of the decomposition process. Before processing, the materials have to be adequately mixed and blended. The water contents of the waste mixture for windrow formation do not exceed 65 – 70 %. The minimum water content is no less as 45%.

Current collection system, statistics on quantities

Vienna currently offers 80‘000 containers for the separate collection of organic waste („Biotonne“), located at more than 31‘000 sites. Some 3‘400 of the “Biotonne” containers are placed in the context of collection banks, the remaining are on separate sites of their own.

For each square kilometre of built-up area (126 km^2) Vienna has 199 Biotonne sites. Each site (mathematically) covers 65 inhabitants or 30 households. The theoretical distance to the next Biotonne site thus is about 35 to 40 metres. Naturally, in the suburban districts, this distance is frequently less than 20 metres. About 29% of the tanks are located on private land.

In less densely populated areas bio beans are located inside of the property, in densely populated areas the beans can be found on collection banks. There are no “Biotonne” containers in the historical city center.

Figure 2. Open Composting Plant Vienna Lobau

Fees

In general, separate collection of garbage is not charged directly, but is covered by the garbage collection fee, together with all other waste collection and treatment costs (with the exception of packaging material).

Composting plant Vienna Lobau

In investigating a proper composting method, the City of Vienna started out from the premise that a process should be found which minimises handling of the rotting material even under conditions prevailing in a big city.

The following criteria were developed for a future facility:

- must allow prompt implementation;
- for future expansion the existing parts of the facility must be used again.
- no investment in facilities for which functionality cannot be guaranteed;
- optimum incorporation of existing facilities;
- no rapid rotting, but a method that takes into account future use of the compost (mainly farms); the high quality of compost depends on high content of humus, humus can be generated only during a slow rotting system
- easy to handle, low trouble-shooting requirements, which eliminates complex rotting systems;
- intelligent choice of location and rotting management, to reduce obnoxious smells.

System description

The composting plant Vienna Lobau is a completely outdoor (open) facility. The total capacity of the facility exceeds 150,000 metric tons per year.

The organic waste generated within the Municipality of Vienna is collected separately in compliance with strict guidelines with regard to composition, pollution and quality, and first given an initial treatment (crushing, screening, conditioning, mixing, etc.) at the compost preparation area of the composting plant Lobau.

During intensive rotting (pre-rotting and main rotting or unit rotting), the material is turned by a purpose-designed machine to ensure oxygen supply which is necessary to achieve a low-smell aerobic process. This stage, which takes about four weeks, is followed by post-rotting (rest phase). During this phase, the material is again turned by other purpose-designed machines (this to avoid a recontamination with pathogen bacteria). The ripe compost is then screened and used for a range of applications. The rotting material is repeatedly checked for quality in the course of the composting process.

Quality control

The collection, treatment and composting methods for organic waste were chosen specifically to ensure quality control of the compost. Quality control itself is performed in three stages.

Stage 1: Examination of the collected waste
Samples are taken in regular intervals from the collected and treated biogenic material and examined particularly for heavy metals in an in-house lab.

Stage 2: Examination of the rotting material
All windrows at the Lobau compost yard are regularly monitored: in intervals of three to four weeks, they are tested for, loss of weight on ignition, nitrate, nitrite, total nitrogen, pH and heavy metals. Water content is being measured weekly, temperature daily. When high heavy metal content is found, the lab management first instructs to have the affected composting material treated separately. If the rate continues to rise, it may be necessary to eliminate the rick from the composting process and use it for, e.g. dump greening or filters. The disadvantage of this method is that substantial batches may be lost for composting. On the other hand it is known that heavy metals are dissolved only during composting when acted on by a number of acids, and are thus spread evenly through the batch so as to allow an analysis. In addition, the use of top-turn systems allows reducing the volume of composting windrows which thus become easier to manage.

Stage 3: Examination of the matured compost
For compost windrows where an in-house lab check finds sufficient maturation and acceptable expected heavy metal content, an external test is made at an outside lab in accordance with the regulations of the Austrian compost ordinance and Austrian Standard S 2203. Some 15 tests of this type are made annually.

Each compost batch in excess of 6,000 m³ (raw material) is given a unique designation. A special computer programme files all data on the rotting process, such as the date of stacking, number and date of turnings, results of accompanying tests, special events, etc., which can be retrieved at any time.

Bio waste preparation

The bio waste preparation plant is organised as a central handling point for all biogenic waste separately collected by the Municipal Department 48 and located within the composting plant Lobau.

All organic waste collection vehicles and other organic waste transports are directed to the preparation plant.

The preparation plant consists of the following sections:

- delivery,
- processing,
- homogenisation,

Delivery
The system distinguishes between „Biotonne“ (i.e. separately collected biogenic kitchen, garden and market waste) and „structural material“ (mostly waste from waste depots, private deliveries, screen overflow from fine compost treatment). The two groups are buffer-stored separately and treated differently. A buffer store holds at most a daily batch, i.e. about 360 tons.

The main difference between these two groups is that the “Biotonne” material is obtained by anonymous collection and must thus be carefully sorted, whereas structural material is checked upon acceptance at the waste depot, so that post-sorting is not necessary.

Accurate knowledge of the collection area (collection routes) also makes it possible to sort „clean“ and potentially „polluted“ “Biotonne” fractions already upon delivery and to feed them to different preparation steps.

All organic waste collecting vehicles and all other vehicles that deliver biogenic waste are routed across a weighbridge located at the Lobau compost yard and which exactly registers the input weight.

It has a capacity of about 150,000 tons per year at one-shift operation. The preparation facility is collected by video surveillance to a central control room and operated from there. The central control room also checks the proportion of structural material to „Biotonne“ material (C/N ratio) which is important for rotting.

Processing
As a first step, the “Biotonne” material is shredded by mobile choppers and screened. The fraction of less than 80 mm is routed to an iron separator; the next step is removing of other foreign materials such as plastics and other non-biogenic waste. It should be noted that the collected waste contains 1-5% in non-compostable substances, which can be concentrated in 20 percent of the mass by preliminary screening and then virtually eliminated by post-sorting. The material (>80 mm) is being incinerated.

Homogenisation
The two material flows are homogenised in a mixing station, which contents of two conveyor belts meeting each other before loading for transport to the composting area. During the mixing phase water can be added.

The homogenisation stage allows also adding a number of other additives such as rock dust or earth.

Immediately downstream of the mixing stage, provision can be made to fit an automatic sampling device for quality control checks of the raw composting material.

Loading for transport

The processed raw material is then loaded onto transporters (skips) of 50 m³ capacity. Currently, the department operates three vehicles of this type, but when required, other transporters can naturally be used as well. Loading is automated and takes 15 to 20 minutes per vehicle.

The raw material is taken to the composting area in a distance of several hundred meters only.

Composting area

Description

The compost yard is located at the edge of the Lobau wetlands to the south-east of Vienna. It consists of two consolidated rick ranges of about 26,000 m² each (together 52,000 m²), subterranean collection tanks for precipitation and seepage water of a total volume of 1,300 m³, and a sealed open water basin. The seepage water is discharged into the public sewage system. Rain water can be stored in the two collection tanks and, if necessary, in the similarly water-proofed open retention basin.

In an emergency the entire rick range is available as a retention basin. This ensures that all polluted water is collected and does not pollute the groundwater.

The yard also features an operations building and laboratory, a garage and workshop and a petrol station.

In addition it has a truck weighbridge, a weather station and a well to draw industrial water.

Also provided are access roads and parking lots. The yard is completely fenced in and is locked after working hours. Provision has been made for a direct railway siding.

The Lobau yard is staffed with nine employees: one manager, one electrician, one laboratory assistant, two engine operators and four truck drivers. Operations are handled by the highly qualified staff using a modem computer system.

Among the machines owned by the yard are:

- 3 wheel-loaders,
- 2 turners,
- 1 tractor,
- 1 irrigation vehicle
- workshop equipment,
- small machines,
- miscellaneous.

Operation

The Lobau yard can treat about 150,000 tons annually in input.

The course of volumes delivered over the year varies little from year to year, so that it is possible to define three phases:

- Phase 1: <6,000 m³/month January, February, December
- Phase 2 : 6,000-10,000 m³/month March, April, July-September, November
- Phase 3: > 10,000 m³/month May, June, October

At about 12,000 m³, the greatest volume is supplied in May, while the smallest quantities (4,000 m³ per Month) are recorded in January and December.

The windrows are placed in lines directly by the skips are turned over at least once a week in the first phase when degradation is most intense (four weeks). For this, a turner is used which is provided with a device for shifting windrows to allow optimum utilisation of the space. The rotting loss considerably reduces the volume of compost, so that the turner can combine several windrows in the course of rotting.

After primary rotting, the material undergoes secondary rotting for one to two months.

The material is irrigated as required.

Once the compost has achieved a suitable degree of ripeness, it is finally screened by mobile drum screens of a mesh size of 10 mm.

The following process parameters are being measured at the windrow core and documented for each windrow each working day during the first 4 weeks of the intensive/ active rotting stage:

- Temperature
- Oxygen (O_2) concentration
- Carbon dioxide (CO_2) concentration
- Methane (CH_4) concentration

Measurement points are set for each 300 m³. The triangular windrows have a height of 2.5 m, a windrow base width of 5 m and windrow length of 120 m, i.e. three measurement points per windrow are required.

At the open composting plant Lobau, monitoring of gaseous emissions is not possible. Measuring gas concentrations and temperatures at the windrow core serves the purpose of documenting a technically correct composting process in a traceable manner.

Neighbours

The compost yard is situated inside a dedicated industrial zone. It is enclosed by forests and fields of the Lobau in the north-west to north-east, and by the OMV and Shell plants on the other sides. The yard is not open to the public. The next publicly accessible facilities (e.g. inns along the New Danube) are at a distance of more than 1000 m. The next housing complexes are more than 2 km away.

Emissions to air

- Odour management: In order to prevent or reduce odour emissions from composting systems to air, the techniques given below are used:
  - Adequate aeration and moisture adjustment during the initial active composting phase. It is vital that aeration via natural convection is realised to ensure sufficient air is supplied to the composting material and ensure the process is maintained under aerobic conditions. During the most active composting stage at higher temperatures, moisture must be monitored and recorded. Water addition shall be recorded on batch records to ensure optimal conditions are maintained.
  - The operator has to mix input materials in order to achieve a consistent and balanced C:N ratio in the batch. Any moist or wet loads accepted are routinely blended with other woody or dry inputs or compost oversize material (compost screenings) upon discharge to reduce the possibility of anaerobic conditions developing and so increasing the potential odour release.
  - When possible, peak impacts can be avoided by timing operations at the site. Weather conditions and wind direction (towards sensitive receptors) have to be taken into account for formation or turning of windrows during when odour emissions are likely to occur. However this should be decided on a site by site basis, as lack of turning may sometimes exacerbate emissions if weather conditions persist. There is a wind sock to monitor wind direction. The weather monitoring data are being used to help determine site activities.
- Dust and Bioaerosols
  - Effective management of moisture, temperature and air supply of all material reduces a risk of generating dust and bioaerosols.
  - The adequate moisture content throughout the composting process is maintained to avoid the composting materials and finished compost drying out and potentially generating dusts when handled. Batch irrigation is being undertaken when the parameters for moisture content fall below the critical limits, but this needs balancing with optimising moisture conditions to enhance screening performance. For this reason moisture adjustments are to be decided on a site by site basis, following an appropriate assessment of the likely impact dust will have on the surrounding environment and moisture levels will have on the performance of screening.

Emissions to water

- All operation areas (waste storage, waste preparation, composting, compost storage) are impermeable.
- Polluted water and leachate are being passed into to the communal sewer system and further to the to the communal water treatment plant.
- Stromwater is originating from roofs or from areas of the site that are not being used in connection with storing and treating waste is being discharged directly to groundwater by seepage through the soil via a soakaway.

Utilisation/application

At the Vienna Lobau site 40‘000 t/a of compost with highest quality can be produced. With its soil/plant subsystem, nature points the way to an almost perfect recycling model. Any interference with the eco-system, such as imbalanced soil tillage, monoculture or removal of organic harvest waste, affects the turnover balance. Around Vienna, humus already disappears at a rate of 2-4 tons per hectare and year. Compost from organic waste is a major supplier of humus, soil improver and nutrient carrier. It thus acts as a fertiliser, even though its dynamic effect differs from that of mineral fertiliser.

Compost from the “Biotonne” in Vienna is used in a number of applications:

- City-owned farming operations,
- City gardens,
- Potting soil production
- Given away to the population (waste depots) and allotment gardens,
- Sale

The matured compost, which is rich in nutrients and humus, is spread on the fields of farmers in Vienna. To this end, the Municipal Departments MA48 (v) and MA49 (Forestry Office and Urban Agriculture) are working closely together to ensure organic waste management in the City of Vienna in the long run, and to persuade Viennese farming operations to change over to organic farming which, considered future-proof, should help to counteract the typical economic problems faced by agriculture.

The use of compost in organic as well as conventional farming is continuously monitored by the Bioforschung Austria (former: Ludwig Boltzmann Institute of Organic

Farming and Applied Ecology). The scientific monitoring programme encompasses the following subjects:

- fertilising effect of organic waste compost on a variety of crops, under a wide range of conditions for cultivation;
- effect of long-term compost application on the nitrogen household of the soil and groundwater;
- examination of the harvest quality (feeding tests, yield assessment).

In parallel, the institute carries out tests and investigations into issues cropping up from current practice, such as dioxin analysis, enhancement of the phytotoxic resistance effect of compost, testing of new composting methods, effects of trace elements on plants and soil.

Continuing this collaboration is seen as a major prerequisite to ensure that organic waste recycling functions smoothly. The project was in operation between 1988 and 2009. The current BIORES-project is a continuation of it. Results obtained so far are highly promising. Even though the changeover to organic farming usually entails a loss of revenues (compared to conventional farming), it can already be confirmed that compost from separate organic waste collection is suitable for use in farming.

The nutrients contained in the compost are organically bonded and thus not available immediately. This must be taken into account in determining the annual application rate. Whereas for the first years, a higher compost application rate (about 40 tons per hectare and year) is possible and even necessary to provide the soil with proper fertilisation, the rate must then be reduced to some 10 tons per hectare and year, to counteract the risk of increasing nitrate leaching into the groundwater.

In the long-term, the Municipal Department MA49 is nevertheless expected to consume 15‘000-20‘000 tons of compost from organic waste recycling per year.

Compost is also given away free of charge in small quantities to all interested private gardeners and allotment gardens, as well as sold. It is expected that future compost production will reach 50‘000 tons per year. Assuming that the free distribution to private individuals will be a maximum of 15‘000 tons pear year, new constomers will have to be found for 10‘000-15‘000 tons per year in the long term. Potential users of compost are companies working for the City of Vienna (reclamation, road construction, residential building) and private farmers in Vienna and Lower Austria.

Summary

The organic waste recycling system in Vienna is based on the principle of straightforward solutions that are safe and have established their value in practical applications.

Separate organic waste collection enables all people in Vienna to contribute to the system, without any disproportionate rise in costs from an excessive container coverage density. Great emphasis is given to ensuring that only clean substances of a suitable type are collected. The „Biotonne“ concept is to be closely linked to „compost“ -not everything that is biologically degradable can be composted under Vienna‘s organic waste recycling concept and should thus not be collected.

The choice and introduction of systems was guided by the principle of operational safety and cost-efficiency. As a result, expensive mechanical systems of the closed type were rejected and open composting was chosen.

Quality assurance has top priority in all sectors of organic waste management. For composting, the main emphasis is on a safe, long-term solution. The composting plant Vienna Lobau is an open composting facility operating according to all BAT-conclusions being in preparation by JRC in Seville.

Selling compost on the free market is naturally desirable, but does not secure the disposal autonomy which is required for a city like Vienna. The consequence was to opt for close co-operation with urban agriculture (Municipal Department MA49).

The system is based on the principle of a locally closed circle. This saves costs, is environmentally friendly and makes it possible for people of Vienna to make a personal contribution to turning their city into an environmental model town.

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Low cost composting options: the case-study of the Municipalities of Argos–Mycenae and Nafplio, Greece

This paper provides information on a low cost composting system within a decentralised solid waste management plant, with the prospect of the wider transferability of such schemes in other similar regions or developing countries.

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Abstract

Currently, incorporating composting in waste management strategies is stipulated by legislation and environmental standards and can be accomplished through several systems, ranging from small to large scale. This article presents the design of a low cost composting system, designed as integral part of the municipal solid waste management plant of two Municipalities in Peloponnese, Greece, the municipalities of Argos-Mycenae and Nafplio. The composting system consists of covered windrows with mechanical turning and can treat approximately 13,800 tons per year, producing about 7,400 tons of finished (refined) compost on an annual base. The operation of the decentralised MSW management plant in these two municipalities is anticipated to replace the current uncontrolled land disposal sites, enhance the environmental protection and prepare the ground for the acceptance and operation of a large-scale centralised Mechanical-Biological Treatment (MBT) plant. The transferability of this system in developing countries or regions facing similar waste generation and management issues is considered high and economically feasible.

Introduction

The European Commission has encompassed the concepts of sustainable waste management and developed its waste policy based on the idea of the waste hierarchy, which ranks waste management options in terms of their environmental impact. According to the revised Waste Framework Directive (2008/98/EC), waste prevention is placed at the top of the ladder as the most favourable option, followed by (in descending order) preparing for reuse, recycling (including composting), energy/material recovery and disposal in properly engineered landfills.

Sustainable solid waste management has moved to the forefront of the environmental agenda, advocating a change of policy, "triggering attitudes and methods that conserve natural resources and reduce the environmental impact of anthropogenic pollutants" (Lasaridi et al., 2014). Sustainable waste management presuppose the equal consideration of economic, social and environmental parameters (McDougall et al., 2001). Lately, the concept of integrated solid waste management (ISWM) is promoted. The United Nations Environmental Programme (UNEP) defines ISWM as "the strategic approach to sustainable management of solid wastes covering all sources and all aspects, generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximizing resource use efficiency". Under the lens of ISWM, organic waste is increasingly considered as a

Technical data:

- The municipal solid waste plant is designed to treat 33,600 tons per year (approximately1 08tn/d), corresponding to a population of 77,400 inhabitants.
- The composting system is designed to receive 13,800 tons per year.
- Estimated compost produced after refinement: 7,400 tons per year.
- The composting process develops in two stages: the first one is taking place in windrows with mechanical turning and covers (1,500 m^2), and the second, maturation stage in open static windrows (500 m^2).

“recyclable” material and a useful resource (Tontti et al., 2011), bringing out organic waste treatment as one of the key tasks of current waste management. On that ground, composting systems, could play an important role in the diversion of biowaste from landfills (Seng et al., 2013), which accounts for approximately 30-50% of the total municipal solid waste (MSW) quantity, depending on the country. The inclusion of composting in the ISWM can be accomplished through several practices, including small, medium and large scale.

Since 2000, waste policies and legislation regarding municipal waste management in Greece have been going through drastic changes. As a Member State of the European Union (EU), Greece had to adjust its legislative framework to comply with the EU legislation. For instance, the European Landfill Directive 31/1999 promotes the gradual diversion of biodegradable waste from landfilling, allowing by 16 July 2016 the landfilling of 35% of the total quantity that was landfilled in 1995. However, for most waste streams, shifts in management, practices in Greece were implemented at a quite slow pace (Lasaridi, 2009). In order to counteract with this delay and catch up with the diversion from landfilling targets set by the EU legislation, the development of small, decentralised municipal solid waste (MSW) management plants was promoted. In many cases, the decentralised MSW plants include composting facilities, which can be constructed and operate in low cost and in short time. The decentralised plants, if properly operated, could prepare the ground for the acceptance of larger plants and be used complementary to them.
This paper presents the design and the development of a low cost composting system within a temporary decentralised MSW management plant, in two municipalities of Peloponnese (Greece). Since the plant can be adapted to suit various socio-economical conditions, the ultimate goal of this article is the wider transferability of such schemes in both developed and developing countries.

Composting as an alternative option

In the last three decades, composting has become increasingly popular, as countries move steadily away from landfilling. Both legislation and environmental standards stipulated “the development of a new generation of composting facilities throughout Europe” (Slater & Frederickson, 2001). A similar distinct trend is also shaped in USA and Asia.

In the European Union it is estimated that the organic material recovery has grown with an average annual rate of 5.3% from 1995 to 2014 (EUROSTAT, 2016). In USA it is estimated that around 254 million tonnes of MSW were generated in 2013, of which approximately 22 million tonnes were recovered through composting (US EPA, 2015).

In late ‘90s, in China approximately 20% of the MSW were treated through composting (Wei et al., 2000). Wei et al. (2000) report that Chinese MSW treatments plants favour the implementation of composting because of three reasons: 1) The MSW stream is unsuitable for incineration due to its composition; 2) The cost of composting is lower than the cost of incineration and landfilling; and 3) Composting and compost use in agriculture are part of tradition.

The inclusion of composting in the waste management systems deems as a necessity in the case of developing countries, where the biodegradable waste accounts for a large part of municipal solid waste. Many research and modelling studies have shown that composting as an alternative to the “traditional” disposal options for organic waste (i.e. landfilling and incineration), could be beneficial for developing countries in terms of organic material recovery, for prolonging the lifespan of the existing landfills, for improving sanitary conditions, and for the mitigation of the greenhouse gases (GHG) emissions (Papargyropoulou et al., 2015, Seng et al., 2013, Zurbrügg et al., 2005, Mendes et al., 2003).

The benefits of composting

Composting transforms, through an aerobic microbial process, raw organic matter into a stable product, the compost. It transforms drastically the various organic substances, mineralising the simpler and easily assimilable and humifying the more complex compounds. In this sense, composting fulfils, the objectives of a closed biological system, promoting the consideration of organic waste as a resource. The potential advantages of a composting system regard the reduction of the waste volume, the reduction of GHG emissions, and the many different uses of composts.

More specifically, as composting evolves, the volume of the composting substrate might decrease up to 50-60%. Therefore, it can be used to reduce the landfilled waste volume, prolonging the lifespan of existing landfills and reducing the need for more space (Slater & Frederickson, 2001, Tchobanoglous et al., 1993). Incorporating composting into a waste management plant, the GHG emissions (from the plant) decrease (Boldrin et al., 2009; Amlinger et al., 2008; Lou & Nair, 2009). Regarding organic material recovery, compost can be mainly used as a soil amendment (depending on its chemical composition, it may also be used as an organic fertilizer), and as a component of growing media in nursery crop sector (Lakhdar et al., 2009; Diaz et al., 2002).

The case-study of Argos – Mycenae and Nafplio municipalities

The Municipalities of Argos-Mycenae and Nafplio are located in the Central and Eastern part of Peloponnese (Greece), with a population of 42,022 and 33,356 inhabitants, respectively, in 2015. The municipal solid waste generation in the Municipality of Argos-Mycenae is 18,712 tons per year, while in the Municipality of Nafplio 14,854 tons per year. The development of a temporary decentralised MSW management plant in these two municipalities is anticipated to replace the current uncontrolled land disposal sites or waste dumps and consequently, enhance the environmental protection, improve the living standards, and prepare the ground for the large-scale centralised MSW plant, which is planned to be constructed in the region of Peloponnese in near future. Harokopio University assisted the two municipalities during the development of their waste management plan and provided guidance regarding the design of the temporary decentralised MSW management plant, including the composting system.

The waste management plant

The temporary MSW management plant is designed to treat 33,566 tons per year (approximately 108 tons per day). It will be constructed in "Grimaria" (Municipality of Argos-Mycenae), covering an area of 6,302 m^2 (Figure 1). The plant will comprise two main units, namely the packaging waste separation unit, and the composting facilities.

The technical requirements for the design of the MSW management plant are presented in Table 1, while the mass balance flowchart of the typical installation is illustrated in Figure 2. The operation of the decentralized MSW management plant is anticipated to provide the following benefits to the municipalities:

- A significant amount of packaging and organic waste will be diverted from landfilling
- CH_4 emissions and leachates in the sanitary landfills will be mitigated
- Hazardous/toxic substances in the composition of waste will be eliminated
- The decentralised plant will cost less and provide better working environment than a centralised one
- It will prepare the public to accept the construction and operation of a large-scale plant within the administrational boundaries of Peloponnese Region.

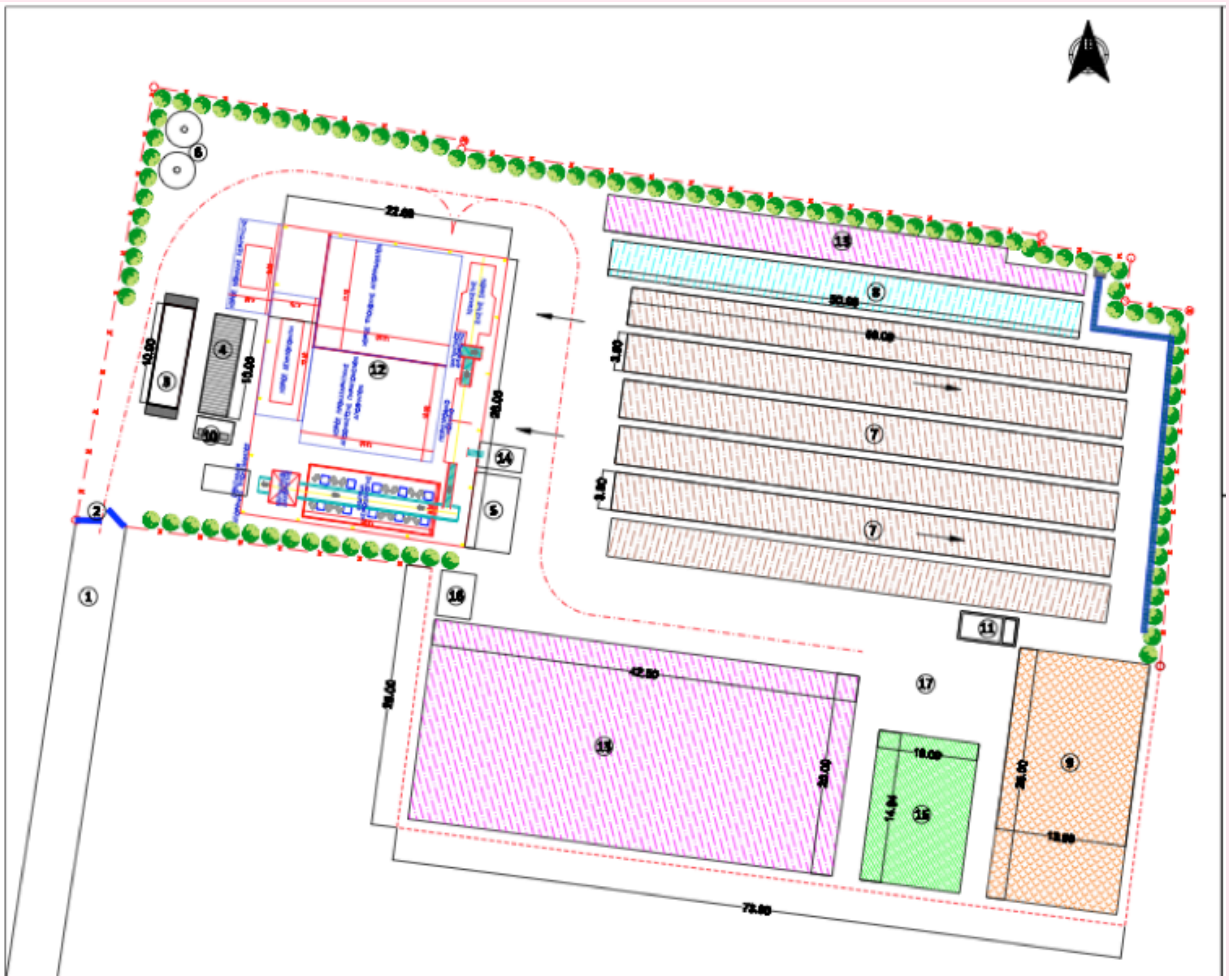

Figure 1. Schematic illustration of the decentralised MSW management plant in the Municipalities of Argos – Mycenae and Nafplio

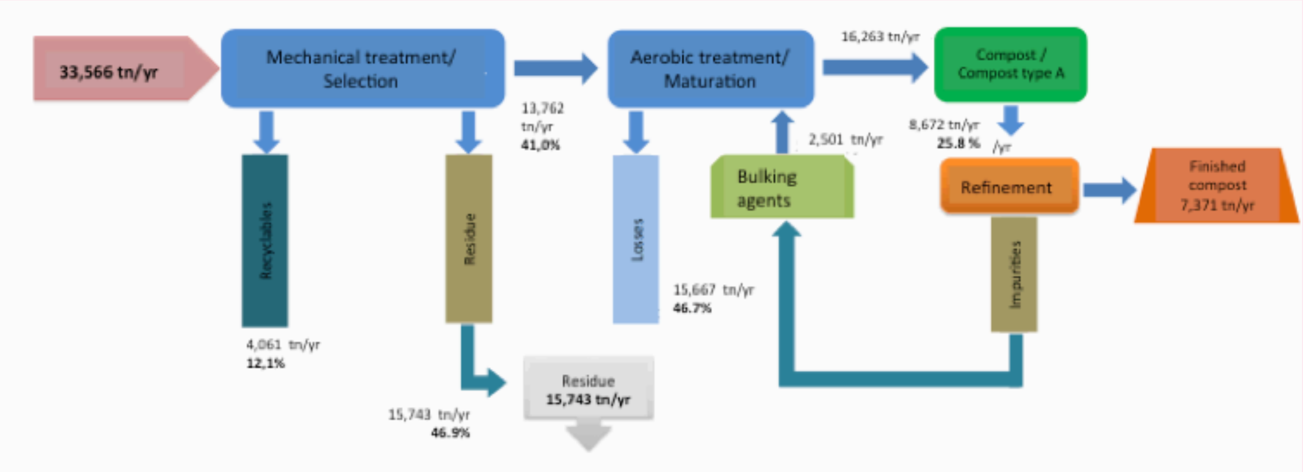

Figure 2. Mass balance of the decentralised MSW management plant in the Municipalities of Argos –Mycenae and Nafplio.

Table 1. Technical requirements for the design of the composting system

Parameter	Set value
Operation time	365 days per year - 15 hours per day
Waste input	108 tons per day – 7.2 tons per hour

The composting system

The development of the composting system was based on the following criteria (of equal significance):

- The cost of the construction and operation has to be low
- Low-expertise personnel has to be required
- The construction and operation has to be in compliance with the National and EU legislation
- The system has to be environmentally sustainable.

Taking under consideration the abovementioned criteria and the technical requirements of the MSW management plant, the composting system is designed to comprise feedstock and preliminary operations facilities (where grinding and mixing are taking place), the composting process facilities (six open windrows with mechanical turning and covers), the maturation phase facilities (static windrows), the refinement facilities, and the facilities for leachates treatment. In the following, the various components will be described in more detail.

Feedstock and preliminary operations facilities

These facilities include the entrance of the feedstock and preliminary operations, such as grinding and mixing. The surface will be properly configured for the avoidance of contamination of the groundwater and soil.

The composting process facilities

Open truncated triangular windrows with a height-to-width ratio of approximately ½ and with mechanical turning, will be installed in an area of 1,500 m^2. The technical and performance parameters of the composting process is shown in Table 2. These windrows will serve the first phase of the composting process, which typically lasts 20-28 days. The configuration of these windrows provides higher degree of homogeneity in comparison to the forced aerated windrows and higher hygienization degree.

The maturation phase facilities

The maturation process (2nd composting phase) will be taking place through the configuration of static windrows in an area of 500 m^2. The technical and performance parameters of the maturation phase is shown in Table 2.

The refinement facilities

These enclosed facilities will include all the refinement operations, such as screening, impurities cleaning and storage in piles.

The facilities for leachates

Floors in all facilities will be configured in order to 'lead" leachates in a storage tank. The leachates will be used in the windrows in order to achieve the proper moisture content of the composting substrate.

Conclusions

A wide range of implemented projects and a multitude of scientific studies demonstrate that composting - granted that it is properly managed and evolved - can provide an effective solution to the organic waste management issue. The apprehension and exploitation of the environmental benefits of composting and compost use create a solid ground for the development of more sufficient and sustainable waste management schemes as well as the rational use of resources. Full scale composting processes comprises within centralised and decentralised municipal

Table 2. Parameters for the configuration of the windrows

Parameter	1st phase	2nd phase
WINDROWS		
Width	3.6-3.8 m	4 m
Height	1.8-2.0 m	2.2 m
Length	50-55 m	50 m
Volume	254-298 m^3	346 m^3
Number of windrows	5-7	2
COMPOSTING MIXTURE		
Daily waste input	65.5-68.6 m^3/day	30.5 m^3/day
Windrow installation	3.9-4.4 days	11.3 days
Composting time	20-28 days	28 days
Volume reduction	35%	18%

solid waste management plants one of the most effective ways to recycle organic waste and promote the circular economy in both developed and developing countries.

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Planting tests with wastewater treatment sludge compost in China

The paper shows that the use of compost from sewage sludge leads to high yields in fruit farming.

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Abstract

In 2020 China is expected to have a sewage sludge generation of 60 million tons without having adequate treatment in place. As a pilot project 40 tons of sewage sludge were processed into compost in the mechanical biological treatment (MBT) plant Gaobeidian. The compost was refined by blending with mineral fertilizer and applied in field testing. The yield from cherry trees was found to be equal to conventional farming using mineral fertilizer. In parallel, the soil properties improved. The economic analysis shows that sludge compost can be produced for 61.5 €/t and refined fertilizer (N-P-K 5-5.5-3) for 122 €/t. The market analysis shows that this price is competitive, since farmers are spending between 305-527 €/t for mineral fertilizer (N-P-K 15-15-15).

Objective

The disposal of wastewater treatment sludge is increasingly becoming a challenge in PR China. In 2008 the government launched a program aiming on reducing emissions from untreated wastewater by means of establishing wastewater treatment plants. By September 2011 3078 wastewater treatment plants were in operation in China with a total capacity of 136 million m^3/day. 1600 plants were under construction. As a consequence a sludge generation of 60 million t per year is expected by the year 2020. An integrated, sustainable national concept for sludge management is still missing. Just one fourth of the facilities is linked to sludge treatment installations, only 60 plants have anaerobe sludge digestion in place. The sludge management is one of the urgent environmental challenges for China. Consequently in the 12th 5 years national master plan the government claimed the goal of establishing sludge treatment for 40 % of the sludge by 2015. In this context the utilization of sludge in agriculture is an interesting option, particularly because in many regions agricultural land suffers from loss of organic soil content and inadequate mineral fertilizing. Since Chinese law restricts the utilization of sewage sludge in agriculture an appropriate sludge treatment is required. The project aims on establishing a high end utilization of sewage sludge in agriculture by means of producing fertilizer. The application of any fertilizer products in Chinese agriculture requires a state controlled approval procedure, which in case of success results in a state issued product certificate. The German project developer AWN Umwelt has conducted this certification procedure during the period August 2014 till November 2015 for a fertilizer enriched sludge compost. The results are presented in this article.

Production of compost

Facility

Since 2006, AWN Umwelt operates as a joint venture partner a wastewater treatment (WWT) plant in Gaobeidian (Hebei province, PR China), a city located 80 km south of Beijing. Between 2008-2011 AWN Umwelt established a mechanical biological treatment (MBT) plant at the same location, which has been transferred to the municipality (Kölsch and Ginter, 2014). The plant consists of a recycling compound and a 4000 m^2 roofed biological treatment area (Figure 1). The biological treatment

Key facts:

- Composting of 40 t sewage sludge and 16.5 t peanut shells
- Planting tests with cherry, apple and wheat at 2 ha testing fields
- Test variation with parallel tests and reference plots (mineral fertilizer, not fertilized)
- Test duration 1.5 years
- Comprehensive marketing study for compost utilization in Rongcheng and Yantai

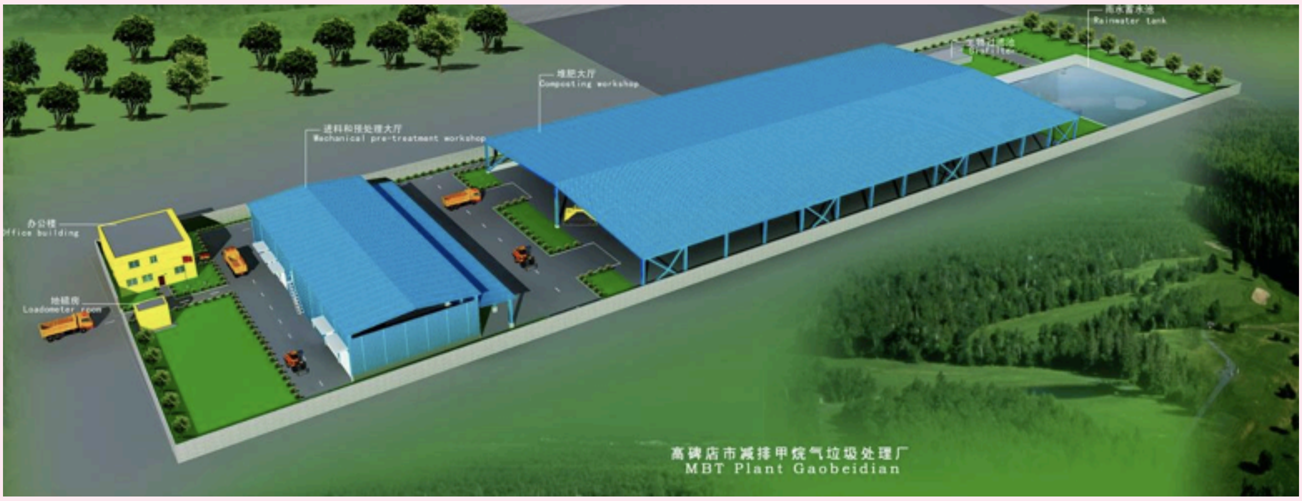

Figure 1. MBT plant Gaobeidian – schematic air view

Figure 2. Preparing of peanut shells

Figure 3. WWT sludge and mixing process

features an actively aerated composting ground (bottom ventilated) and a mobile windrow turner. The annual capacity is 40.000 tons. The compost has been produced in the MBT facility using sewage sludge from the WWT plant Gaobeidian.

Composting process

Approximately 40 tons of WWT sludge have been treated in the facility. Alternative structure materials had been investigated in trials. Finally, grinded peanut shells were selected, because this structure material was easier to process and has a better degradability and a higher water retaining capacity than the alternative (cheaper) corn

Figure 4. Composting windrows

cobs (Figure 2). The sewage sludge (approx. 83% moisture content) was mixed with 16.5 t of peanut shells (approx. 13% moisture content) and stocked onto windrows, together with 4.66 t inoculated bacteria material. Figure 3 illustrates the mixing process.

After setting up the windrow heaps the temperature inside the windrows (Figure 4) increased up to 65°C during the first 3 days. Despite the active aeration of the compost windrows, a lack of oxygen occurred temporarily in the core of the windrows, which was eliminated by frequent turning the windrows. In order to increase the porosity of the material, the height of the windrows had been decreased by dividing them during the following days. The total treatment time was 3 weeks.

The final product was analyzed in the laboratory at Yantai University. Table 1 shows the results in comparison to German (Düngemittelverordnung DÜMV) and Chinese legal standards (organic fertilizer directive NY 884/2012). The input concentrations of the WWT sludge are listed as a reference.

The Output Material shows relatively high values for nutrient content (N+P+K = 7,61%). Compared to the input content, heavy metal concentrations had decreased during the composting process, which is partly owed to dilution effects due to added (clean) structure material.

Production of biofertilizer

Market analysis in the targeted project region Rongcheng (Shandong province) had obtained that local farmers are not very interested in using pure sewage sludge compost as organic fertilizer due to its limited fertilizing effect. Therefore, the idea was developed increasing the market chances by refining the sewage sludge compost by means of adding mineral fertilizer. In August 2014 the compost from Gaobeidan was transported to Yantai for further treatment and finishing. Depending on the required nutritive compounds for the organic fertilizer, various mineral fertilizers had been added to the compost. Applied were following:

- diammonium phosphate DAP (N-P-K: **18-46**-0), $(NH_4)_2HPO_4$
- urea (N-P-K: **46**-0-0)
- potassium sulphate (N-P-K: 0-0-**50**), K_2SO_4

Agricultural planting tests

Background

The Chinese law requires on site field planting tests for fertilizer products. test have to be carried out in parallel and redundant testing plots on different soil types over a full harvesting period with the plants, the fertilizer shall be approved for. The procedure includes reference plots

Table 1. Laboratory analyses of input and output materials of the composting process compared to legal standards

Parameter	Unit	Sewage sludge	Compost	Chinese standards (NY 884/2012)	German standards (DÜMV)
pH	-		6.48	5.5-8.5	-
moisture content	%		21.9	< 30	-
loss on ignition	%		46.1	> 40	-
N	%		2.97	-	-
P	%		3.89	-	-
K	%		0.75	-	-
As	mg/kg	15.6	11.7	15	40
Cd	mg/kg	0.045	0.54	3	1.5
Cr	mg/kg	380	130	150	300
Pb	mg/kg	98	24	50	150
Hg	mg/kg	1.55	0.05	2	1
Zn	mg/kg	2378	270	-	5000

under conventional fertilizing and other plots without any use of fertilizer. The targeted project region (and anticipated future market) is well known for the production of fruit, particularly cherry and apple. The profitability of fruit production is much better than for grain, thus fruit farmers were identified as preferred potential customers. However, wheat farmers are also seen as potential customers, since the total fertilizer consumption is much higher than in fruit farming due to larger planting areas.

Test results - Cherry

As an example the test results for the cherry trees are presented in detail. The testing field was situated in Songjiazhuang (Laishan district, City of Yantai, Shandong province). The location lies 56 m above sea level, the annual rainfall is about 652 mm on average. The annual average temperature is

11.8 °C. Because of its intensive sunshine (2698 h/a or 5224 MJ/m²) and long vegetation periods of about 210 days, the city of Yantai is famous for its fruit growing, especially apples, cherries, pears and grapes.

The testing field with a total area of 9.15 Mu (6100 m²) had been divided in 2 sections for testing purposes. On the northern block (3.3 Mu or 2200 m²) 195 cherry trees had been planted, on the southern block (5.85 Mu or 3900 m²) 350 cherry trees. Prior to the testing campaign the fields were cultivated in a conventional way. The soil shows a pH value between 5.2-5.4 and an organic content of 0,64-0,94 %.

Different fertilizer applications were carried out on the fields: Table 2 summarizes the applied nutrition amounts and concentrations.

- I refined AWN sludge compost (N-P-K: 4.8-5.5-2.1 or 5.3-5.8-2.4)
- II standard mineral fertilizer for cherries (N-P-K: 15-15-15)
- III reference field, unfertilized

Table 2 illustrates that the load per tree is 2.5 kg (conventional) and respectively 2.5 kg or 5 kg (AWN Mix), what results in lower nutrient supply by the AWN mix. In conventional fertilizing the nutrient provision is 375 g N-P-K per tree, whereas for the refined compost fertilizer 240-275-105 g or 133-145-60 g N-P-K was applied. The planting test started in August 2014 and ended June 2015. Figure 5 shows the bag packing and field application of the refined sludge compost.

Table 2. Planting tests cherry - application of fertilizer (per tree)

		N	P	K		N	P	K
	dose [kg/tree]	[%]	[%]	[%]		[g]	[g]	[g]
Cherry north								
I: AWN-Mix	5	4,8	5,5	2,1		240	275	105
II: Cherry fertilizer	2.5	15	15	15		375	375	375
Cherry south								
I: AWN-Mix	2.5	5.3	5.8	2.4		133	145	60
II: Cherry fertilizer	2.5	15	15	15		375	375	375

Figure 3. Flow chart of the treatment & reuse system (source: ESF; 2014)

Table 3. Harvesting yield from cherry testing fields

Fertilizer	Load kg/tree	N-P-K g/tree	Yield north kg/tree	Yield south kg/tree
I: AWN-Mix	5	240-275-105	28.1	
	2.5	133-145-60		32.9
II: Mineral	2.5	375-375-375	29.3	
	2.5	375-375-375		31.7
III: without	0	0-0-0	22.9	
	0	0-0-0		25.4

Table 4. Soil properties

Fertilizer	pH -	Organic content %	Alkali-hydrolysable N mg/kg	Available P mg/kg	Available K mg/kg
Start	5.4	0.94	76.5	52.8	177.5
I: AWN-Mix	5.7	1.13	94.5	59.9	183.8
II: Mineral	5.4	0.88	86.1	55.7	181.3
III: without	5.8	0.63	61.8	26.5	82.9

At the beginning of the flowering phase there were no visible differences between variants I and II, in the full flowering phase only slightly notable differences. A remarkable difference was noted in comparison to the non-fertilized trees. Also during the fruit phase only small differences were observed between the fertilized trees, in contrast to the non-fertilized trees which carried less and smaller amount of fruits

The yield is the most relevant criteria for evaluation of the fertilizing effect. Table 3 shows the results for the cherry planting test. The yield results prove that the southern testing area generally showed higher yields than the northern area. In both areas the differences between mineral fertilizer and refined sludge compost were very small (- 4.1 % and + 3.8 %), while the non-fertilized reference fields obtained significantly smaller yields (- 22.7 % and - 29.5 % compared to AWN mix).

Before the test and during the harvesting time the soil properties were analysed in the laboratory. The results are presented in Table 4.The results illustrate that the application of refined compost sludge increases the organic content in the soil as well as the availability of nutrients. It indicates that the compost improve the soil structure and acidification and enhance the nutrient holding capacity reducing the loss and leaking of nutrients. However, the investigation period of 1 year is too short to reliably assess the long term effects in soil improvement.

I (AWN-Mix) **II (Mineral)** **III (without)**

Figure 6. Wheat before harvesting

Table 5. Cost for compost production

		Unit cost	Units	Total cost	Cost/ton compost	
		[€]		[€/year]	[€/t]	[RNB/t]
Input						
WWT sludge	100 t/d			(253'472)	(8.86)	(64)
Structure						
Peanut shells	25 t/d	97	9'125	887'153		
Corn cobs	10 t/d	43	3'650	157'153		
Corn straw	15 t/d	25	5'475	136'875		
Total structure				**1'181'181**	**41.28**	**297**
Operation						
Personnel				54'000	1.89	14
Maintenance				92'754	3.24	23
Consumption				97'600	3.41	25
Depreciation				334'483	11.69	84
Total operation				**578'837**	**20.23**	**146**
Grand total costs (for 28.613 t output)				**1'760'018**	**61.51**	**443**

Other tests

Similar planting tests have been carried out for apple trees and wheat. The total testing area for all tests comprised of approximately 2 ha. The field results for all agriculture products are comparable. The wheat showed even larger differences in the plant appearance due to the improved water retaining capacity of the soil. Generally, the effect of improved water supply for the crops was easier to observe with grain than with fruit trees (Figure 6).

Technical application

Economic analysis

The costs for the production of sludge compost have been calculated in a feasibility study for a facility in Rongcheng (Shandong province). The facility is designed for a capacity of 150 t/day (100 t/day sludge + 50 t/day structure material). Total investment is estimated to 3.3 million € excluding land acquisition and engineering. The costs for compost production in this facility are estimated to 61.5 €/t (443 RNB) not considering revenues from sludge disposal. The cost breakdown is shown in Table 5.

The cost estimation indicates that the largest portion of production costs refer to the acquisition of structure material (2/3), in particular for the peanut shells, which have currently a market price of 100 €/ton. Thus, the costs for the structure material include are still a large opportunity for savings. The processing costs (O+M) represent a small portion of the total costs (14 %), only. It might be reasonable to process cheaper structure materials, even if that would require longer treatment periods or more comprehensive pre processing. Further, the calculation does not consider revenues from the sludge disposal, which are expected to 50-80 RNB/ton.

The costs of refining the sludge compost into a fertilizer, which is comparable to the one used in the planting tests, are summarized in Table 6. The total costs for the refined sludge compost (N-P-K 5-5,5-3) are 122,1 €/t. The mix contains 87 % of sludge compost and 13 % mineral fertilizer. The cost breakdown shows that the sludge contributes less than 50 % to the final costs, which makes almost the same share as DAP and potassium sulphate have.

Compost marketing

A comprehensive market analysis has been elaborated during the feasibility study for the facility. As in many places worldwide the acceptance of the organic fertilizer by the farmers is limited and needs strong and effective awareness raising activities. Comparing simply the fertilizing effect of the refined sludge compost, the farmers would have to apply about three times the amount of fertilizer than exclusively using mineral fertilizer, Thus, the total competing costs would be 2637 RNB and 366 € per batch, respectively. Considering additional revenues from sludge disposal (gate fees), the total costs could be reduced to 2469 RNB and 343 € per batch. The market analysis revealed that fruit farmers currently pay between 2200-3800 RNB/t for mineral fertilizer (equivalent to 305-527 €/t). Thus, the AWN-Mix is situated rather in the lower price range of the fertilizer market. Positive long term effects and improvements in nutrient availability as observed in the planting tests have not even been considered, yet. From this aspect the marketing prospects are promising, however farmers acceptance and innovation capacity are still seen as a major constraint and a significant project risk.

Table 6. Cost for compost refinement

	Input		N	P	K	C	Costs Input	Costs Mix	
	[kg]	[%]	[kg]	[kg]	[kg]	[kg]	[RNB/t]		[€/t]
Sludge compost	1000	87	29.7	38.9	7.5	461	443	386	53.6
Urea	40	3	18.4	0	0	0	2712	95	13.2
DAP	52	5	9.4	23.9	0	0	3950	179	24.9
Potassium	54	5	0	0	27	0	4650	219	30.4
	1146		57.5	62.8	34.,5	461		**879**	**122.1**
	N-P-K-C [%]		**5.0**	**5.5**	**3.0**	**40.2**			

Way forward

AWN Umwelt is currently developing the business model for the planned facility and is moving forward towards implementation.

Conclusion

Composting of wastewater treatment sludge can be a reasonable and environmental sound solution for the treatment and disposal of sludge. Refining the compost with mineral fertilizer can improve the marketing opportunities of the compost. The main cost factor of the compost production is the structure material. Many of the attractive materials are already otherwise utilized in agriculture and they have a (high) market price. However, regarding the marketing of compost the price is just one aspect. The major constraint results from the low acceptance and the lack of innovation by the farmers. Setting up a composting facility requires careful assessment of the framework conditions in order to make the project viable.

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