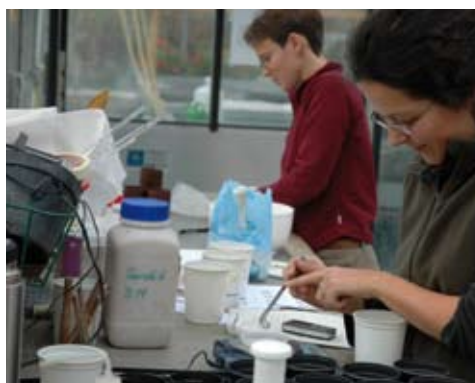


Compost and digestate: sustainability, benefits, impacts for the environment and for plant production

Proceedings of the international congress CODIS 2008

February 27-29, 2008, Solothurn, Switzerland



Edited by Jacques G. Fuchs, Thomas Kupper, Lucius Tamm & Kaarina Schenk



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for plant production**

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Session 1:

The state of biogenic waste treatment in Switzerland and Europe

The Swiss environmental policy and the use of biomass

G rard Poffet¹

Key words: environmental policy, resources policy, biomass, recycling, waste management

Abstract

The Swiss environmental policy aims to ensure that our natural resources such as air, water, soil, forest and landscape are maintained and utilized on a long-term basis in the interests of society and the economy. Our environmental policy is thus also to a large extent a resources policy. Its main task is to reconcile the differing requirements of the natural resources. Biomass comprises many different materials, such as wood, farm manure, plants, biowaste and many others. The big challenge consists in reconciling the varying requirements and aims of the protagonists such as agriculture, the timber industry, environmental protection and the energy industry and so ensure that the use of biomass is optimal for the environment, too.

Environmental policy in Switzerland

The basic principles of Swiss environmental policy are set down in the Federal Constitution of the Swiss Confederation (Article 74 – Protection of the Environment). According to this article, people and their natural environment must be protected against harmful or nuisance impacts. The basic principles for sustainability are also defined (Article 73 – Sustainable Development). The Confederation and the Cantons aim for a lasting, balanced relationship between nature and its capacity for renewal on the one hand and the wear and tear caused to it by humans on the other.

The Federal Office for the Environment (FOEN) is the Swiss Federal Government's centre of environmental expertise. It makes a contribution to the long-term upkeep and use of natural resources such as air, water, soil, forest and landscape.

The different demands on the natural resources have to be reconciled with one another during this process. Environmental policy is thus to a large extent also a resources policy and is closely tied up with economic and social policy. As the responsible Office, the FOEN seeks solutions for environmental protection which also take into account social concerns and the demands of the economy. Environmental protection is carried out as far as possible on the basis of voluntary measures and incentives; prohibitions and sanctions are to be kept to a sensible level and constantly challenged. Grants serve at best as an incentive to voluntary measures.

Because it is an economic policy, environmental policy is also an innovating policy and creates jobs. Environmental policy is also a policy that applies across the board and affects other policy areas such as traffic, energy, agriculture or finance and tax policies, town and country planning and health policy.

Based on the sustainability strategy of the Department (Environment, Transport, Energy and Communication DETEC), and within the context of the resources policy, the FOEN pursues the following goals in four important areas that are essential for nature, society and the economy: safety, health, raw materials and natural diversity.

Safety: This means the optimal protection of life and human goods from natural hazards and those hazards that are caused by people themselves through their interaction with the environment. On the one hand, this means prevention (minimizing risks), on the other, assistance in the case of damage (coping with disasters).

Health: Human impact on the environment is to be managed so that any negative effects that result from it can be kept to a minimum.

Raw materials: The FOEN contributes to the maintenance and long-term use of natural raw materials (production factors) such as timber, drinking water, the soil, landscapes that are attractive to tourists, recreation areas or even high-quality residential areas.

Natural diversity: The diversity of species of animals and plants in their natural habitat is to be maintained or, if need be, promoted.

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In order to achieve these goals the FOEN has the following tasks:

- To monitor the environment and so provide a basis for economic use of the resources
- To prepare legislation establishing a comprehensive and coherent policy for the sustainable use of natural resources and for risk prevention
- To implement the legal principles, to support the implementation partners as well as to give information about the state of the environment and the opportunities for using and protecting natural resources.

The challenge of Swiss environmental policy consists in organizing access to the natural basis of life in such a way as to optimally balance the needs of society, the environment and the economy. This must be carried out in cooperation with and in constant dialogue between the FOEN and other Federal Offices, the Cantons and partners from politics, the economy and society.

Biomass in Switzerland

Biomass is the term for all organic material produced by photosynthesis, whether directly or indirectly, that has not been altered in the course of geological processes. This is in contrast to fossil biomass, such as oil, coal and gas.

The concept of biomass comprises a multitude of materials, such as timber, farm manure, plants, biowaste and many others. This wide variety of materials and definitions shows that the concept of biomass is connected to many activities and therefore also to many protagonists. The big challenge consists in reconciling the different requirements and objectives of the protagonists, such as agriculture, forestry, environmental protection and the energy industry, and thus to ensure *that the use of biomass is optimal for the environment, too.*

As fossil fuels become more scarce and climate problems arise, the use of renewable energy arouses increasing interest amongst the Swiss population, as well as in research institutions, in administrative facilities and in the industry, too. At the present time, around 85% of energy consumption in Switzerland is from non-renewable sources (fossil and nuclear energy). Biomass is the second most important renewable energy source in Switzerland after hydroelectricity. The use of biomass for energy in the form of heat, electricity and fuel can make an important contribution to achieving Switzerland's energy and climate policy objectives, to reducing dependence on non-renewable energy forms and to improving supply reliability. However, the available amounts of biomass and so the theoretical potential are limited in Switzerland, because of the climatic conditions and the available forested and agricultural areas. Plants that have been planted only for the purposes of energy production play no significant role in Switzerland today.

For environmental policy, the priority is on the recycling of biomass, so as to close the material cycles. The example of manure can be mentioned here. A further example is the local timber industry in which recycling also plays a significant role. However, the uses of biomass for recycling and for energy production are not necessarily mutually exclusive. This is shown by the anaerobic digestion of biowaste, one of the themes of this congress. If suitable biowaste is correctly treated, then energy can be produced on the one hand and on the other hand the digestate sludge may be used as a good fertilizer for agriculture, after an appropriate post-maturation phase.

During the current decade, the amount and quality of biomass in Switzerland have constantly been changing. For example, in the light of the necessity to find substitutes fossil fuels, energy recovery has moved into the foreground of the discussion. Several studies relating to the potential of different options for the management and exploitation of various types of biomass are being prepared, worked on, or have just been completed. The legal requirements for the transport and use of certain types of biomass are being changed. The following table (Tab. 1) shows the complexity of biomass usage and the large number of protagonists, some of whom are in competition with one another. In Switzerland the material flow of biomass can be divided into three sub-systems: production, processing and usage/disposal. The various processes listed in the table 1 are classified within the three sub-systems.

Tab.1: Three Sub-systems of the Material Flow System “Biomass in Switzerland“ - Production, Processing, Usage and Disposal with the Corresponding Processes

Production	Processing	Usage and Disposal
<i>Plant production</i> <ul style="list-style-type: none"> • agricultural plant production • seed • harvest residues • fodder plants 	<i>Food industry</i> <ul style="list-style-type: none"> • production, processing, sales, import & export of food (not meat products) 	<i>Consumption of goods</i> <ul style="list-style-type: none"> • consumption of edible and inedible biomass by the Swiss population
<i>Animal husbandry</i> <ul style="list-style-type: none"> • agricultural animal husbandry • game • fish • production of fodder • farm fertilizer (liquid manure +dung) • slaughter animals, animal products 	<i>Timber and paper industry</i> <ul style="list-style-type: none"> • processing, sales, import & export of raw and semi-processed products • waste wood • used paper • cellulose 	<i>Energy use</i> <ul style="list-style-type: none"> • use of biogenic energy sources as fuel
<i>Forestry</i> <ul style="list-style-type: none"> • plant biomass production in the Swiss forests (timber, rind, leaves) 	<i>Meat processing</i> <ul style="list-style-type: none"> • slaughter of animals • sales, import & export of meat • meat products • processing of cadavers 	<i>Sewage works</i> <ul style="list-style-type: none"> • communal or industrial wastewater treatment in order to eliminate the organic matter from the water
	<i>Processing of energy resources</i> <ul style="list-style-type: none"> • preparation and processing of biogenic raw materials for energy use 	<i>Fermentation</i> <ul style="list-style-type: none"> • anaerobic treatment of biowaste, farm manure, sewage sludge
	<i>Other industries</i> <ul style="list-style-type: none"> • processing, sales, import & export of biomass that is not relevant to the production of foodstuffs, meat products, timber products or fuels 	<i>Composting</i> <ul style="list-style-type: none"> • composting of biowaste
		<i>Industrial incineration</i> <ul style="list-style-type: none"> • incineration of sewage sludge • cement works
		<i>Solid waste incinerator</i> <ul style="list-style-type: none"> • incineration of biowaste
		<i>Landfill</i> <ul style="list-style-type: none"> • landfilling of incinerator residues

Biomass in Switzerland's waste management industry

In the use of biomass in Switzerland, two goals of the Swiss waste management policy are of central importance:

- In the area of raw material usage, the waste management policy of Switzerland pursues the aim of making a contribution to the sustainable use of non-renewable and renewable raw materials. In this way environmental pollution should be lessened and the consumption of raw materials reduced.

The disposal of waste is the last stage in the life-cycle of a product. Waste management policy is therefore an important part of the efforts towards the sustainable use of raw materials and so of biomass. For this reason, the second objective of the waste management policy is also relevant for biowaste. This objective is:

- Waste disposal must be environmentally compatible. Noxious emissions into the environment should be further reduced wherever this is technically possible and economically acceptable.

Around 800,000 tonnes of biowaste are processed each year in compost and digestion plants in Switzerland. Composting and anaerobic digestion are therefore important types of waste treatment and are ecologically and economically of great significance, making an important contribution to the waste management industry within Switzerland. The organic substances contained in waste are energy sources that can be used directly through incineration in municipal solid waste incinerators (MSWIs), cement works and industrial furnaces or that are suited to the production of biogas by anaerobic digestion. Thus in 2006, for example, a quantity of around 145,000 tonnes of green waste were processed in the digestion plants in Switzerland. 50% of the electricity produced in MSWIs counts as renewable energy when the proportion of biomass in the waste is at this level. MSWIs generate over four fifths of the total electricity coming from renewable energy sources and so are by far the most important producers. The production of electricity and heat by MSWIs covers around 2 percent of the entire end consumption of energy in Switzerland.

The production of compost and digestate and their use correspond to the basic principle of sustainability in that material cycles are closed. Their use as fertilizers and in improving soil quality are two of the most important agronomic properties of these products. Compost and digestate may however contain pollutants which should not be allowed to accumulate in the soil, as they may have adverse effects. As a consequence of the BSE crisis and the debate about use of sewage sludge as a fertilizer,¹ compost and digestate, which are defined as recycling fertilizers in Swiss legislation, have also come in for criticism. Compost and digestate can only be marketed in the long-term if it can be proved that their pollutant content is at a minimum level and that the use of these recycling fertilizers enhances the quality of the soil.

Two studies were commissioned by the FOEN, the Swiss Federal Office of Energy (SFOE), the Federal Office for Agriculture (FOAG) and the Canton of Zurich, in close cooperation with the biowaste sector. Their aim was to evaluate the risks and benefits of biowaste processing in Switzerland on a scientifically sound basis. The first study aimed to show whether compost and digestate introduce organic pollutants into the environment and whether this has effects on the soil flora and fauna. The second study investigated the benefits of compost and digestate for the environment, for soil fertility and for plant health.

The results of the in-depth studies show that the large majority of compost and digestate in Switzerland is of good or very good quality. To use compost and digestate successfully it is necessary to select the right product for a particular application. Now is the time to put the positive results into practice. The aim is to gain acceptance for fertilizers made from compost and digestate. These products can only be marketed in agriculture, in horticulture and to private customers if their content in pollutants remains minimal and if their properties as soil improvers and sources of nutrients are recognised. With the appropriate quality assurance and good marketing strategies for compost and digestate it may be possible to convince the public of the value of the products.

The conclusion of these two important projects which are bringing to light many new facts on the biological parameters and the occurrence of organic pollutants, both those that are well known and those that have appeared recently, is the reason for this Congress. Subjects to be discussed will be the effects on the environment and on plant production of compost and digestate and the production of renewable energy. This illustrates the wide-ranging scope of the topic of biomass.

¹ banned in Switzerland since 1.10.2006 (with some exceptions admitted until 1.10.2008)

Energy from biomass and related policy

Michael Kaufmann¹

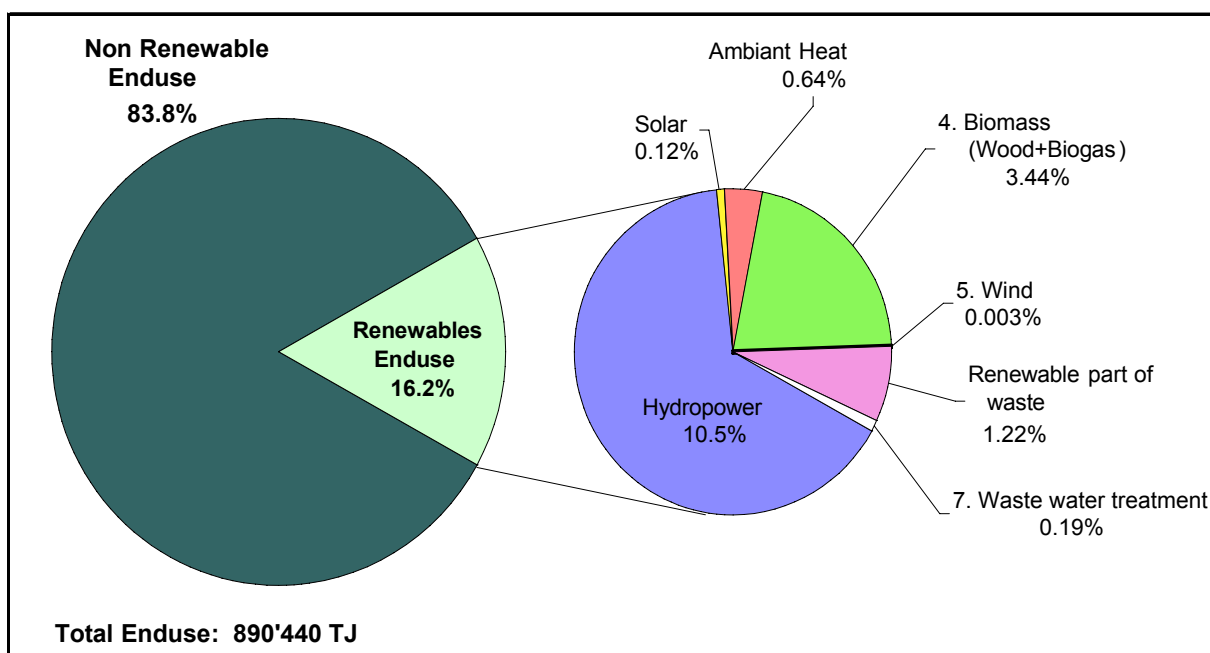
Abstract

Switzerland is not only famous for its hydropower production. It is also a traditional “biomass country”, but only few people are aware of that. Let me explain: Our forest industry is most famous for its first quality wood production – first quality with reference to material quality on the one hand and sustainability aspects in the production on the other hand. Residues from wood production and processing are being used as combustible in combined heat and power plants (CHP) or in wood boilers and stoves. Looking at the agricultural sector, a major part of the Swiss farm land is actually grassland. So the production of meat and dairy products is most important. Therefore our farmers produce a lot of manure which can be used as a feedstock for agricultural biogas plants. Most of the municipalities have organised source separated waste collections in order to either convert the organic fraction into compost or to energetically utilise it in an industrial biogas plant. Such a system has been developed in Switzerland by the Kompogas company – worldwide one of the most successful and efficient systems to produce biogas from organic waste.

Beginning on a small level...

Apart from our famous hydropower which covers almost 60 % of the Swiss electricity production the other renewable energy sources still contribute little to the overall energy production in Switzerland at the moment (2005): Only some 4 % of our energy consumption is covered by „new renewable energy sources“. In the electricity sector it is even worse: green power from new renewables covers roughly 2 % of the electricity consumption.

Energy production from biomass is even on a much lower level. More than half of the energy from new renewables comes from waste incineration. And only about 23 % of the new renewable heat production is covered by biomass. The percentage in power generation is even lower with about 13%.



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A few years ago, the utilisation of Swiss biomass was not a big issue in the energy discussion. Apart from some research and the construction of a few pilot and demonstration plants one wouldn't notice much activity in the field. Even the Swiss farmers' organisations didn't have a biomass strategy nor did they implicate the use of biomass in their political activities.

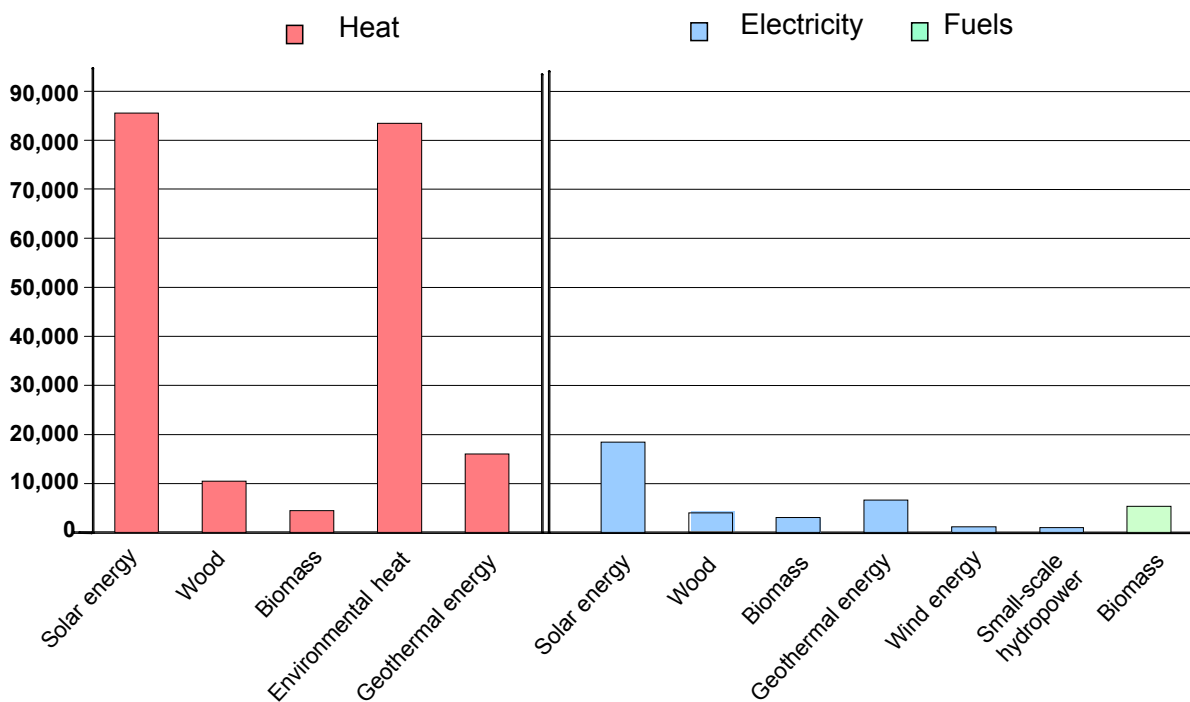
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Nowadays everything has changed – even in Switzerland: With regard to the climate change discussion, the persistently increasing oil price and a possible gap in the energy supply – particularly in our domestic electricity production – there is strongly growing interest in renewables, among others naturally on biomass. In parliament farmer politicians were the first to make proposals for feed-in tariffs and subsidy-programmes for renewable heat between 2005 and 2007 and they were strongly involved in the tax exemption for biofuels as well.

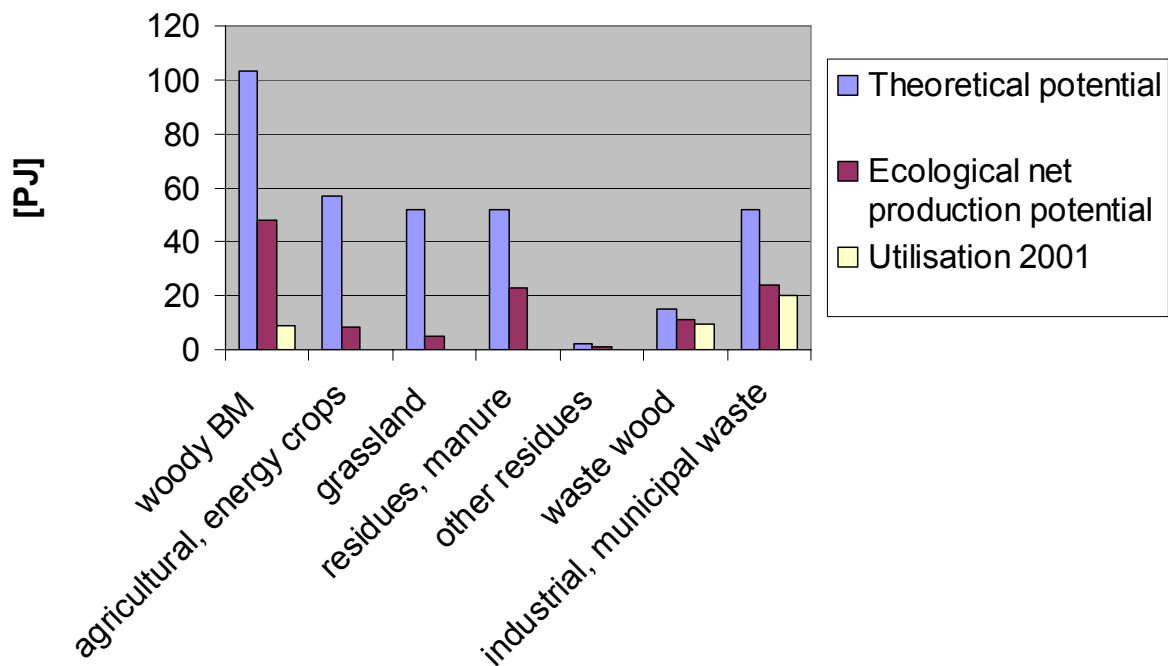
The big Swiss power utility companies – so far rather reluctant with their commitment for the renewables - invest nowadays in small hydropower, wind energy, photovoltaics and in energy production from biomass. One example: In 2005 AXPO, one of the biggest power supplier in Switzerland, set up a renewable programme and created a fund with some 150 million Swiss Francs per year. Main objective of this programme is to increase the energy production from renewables. In 2007 the same company acquired 49% of the shares of the Swiss biogas pioneer Kompogas.

Interesting potentials

A boom in the field of the renewables in Switzerland is no longer unrealistic. Although the still existing potentials in big hydro power are limited, there are interesting potentials among the new renewable energy sources, particularly in the biomass sector. Our potential study (SFOE 2004) shows that the ecological potential for energy production from biomass is about 2 to 3 times the present-day utilisation. Example: Austria covers about 20 percent of their heat demand with wood energy. In Switzerland the bioenergy share of the total end use stays at about 4 to 5 percent with an ecological potential of at least 10 to 15 percent.



As a matter of fact, Swiss potentials compared to nowadays energy production from biomass are quite interesting also from an economical point of view: The current oil price makes wood energy, for example wood pellets, quite competitive. A similar situation can be observed for larger co-generation units running for example on wood-chips.



New instruments and incentives for renewables in Switzerland

This interesting situation for renewables in Switzerland is currently sustained by new policy instruments which are being implemented over the next months, mainly becoming operative from the beginning of 2009.

In general there are three measures that are already decided either by parliament or by the Swiss Federal Council: Feed-in tariffs for renewable electricity, tax exemption for biofuels and more subsidies for heat from biomass – especially for wood. While the last item still has to be accepted by the Federal Council (decision scheduled for February 2008), the tax exemption for biofuels is now ready for introduction. In order to achieve a full tax exemption the Life Cycle Assessment (LCA) of the corresponding process and product is taken into account. Biofuels from waste will be detaxed without LCA check. The guidelines are being prepared by the Swiss Federal Office of Environment. This regulation is binding upon biofuels produced in Switzerland but also upon imported biofuels.

The most important instrument, completed after several years of hard work in parliament, is the support mechanism of feed-in tariffs for electricity from renewable energy sources. The corresponding change of the energy act was decided in March 2007. Feed-in tariffs are guaranteed for all the new renewables including small hydropower up to 10 MW. Together with the new energy supply act which introduces step by step the market liberalisation for electricity in Switzerland starting in 2009, this new incentive for renewable power is in preparation at the moment. The Swiss Federal Council will decide on the detailed directives in March 2008. The mechanism will be operative at the beginning of 2009.

New support schemes for renewables in Switzerland

Feed-in tariffs for renewable electricity

- Objective: + 10% of renewable electricity based on the demand in 2004 (+ 5'400 GWh)
- Feed-in tariffs for all renewables (hydropower up to 10 MW)
- Feed-in tariffs covers the production costs
- Limited to maximum costs of 0.6 Swiss cents / kWh (for the consumer)
- Limits for PV (yearly quota)
- Mechanism starts in January 2009

Tax exemption for biofuels

- Tax reduction for natural gas as a fuel
- Full tax exemption for biofuels from waste
- Full tax exemption for biofuels from energy crop depending on the LCA (criteria for an appropriate check are being drawn up)

The feed-in tariff mechanism is well known in Europe. Already for several years Germany, Austria, Spain, Denmark, Italy and some other countries have successfully been working with similar support schemes, particularly in wind energy, photovoltaics and energy from biomass.

Developing this support mechanism, our office tried to find the best formula in benefitting from several years of experience. As a result we now have a typical Swiss framework which combines the guaranteed feed-in tariffs on the one hand and contingents limiting the additional cost for the end-consumer to a maximum of 0.6 Swiss cents per kWh on the other hand.

In spite of these rather difficult restrictions Switzerland will have funds available for these subsidies in the order of 320 million Swiss Francs per year till 2030. The Swiss Federal Office of Energy estimates that only about 50 percent of the existing potentials can be achieved thanks to the feed-in tariff mechanism. The other 50 percent will have to be covered by direct marketing of green power and other voluntary measures of the utilities' sector and the suppliers. Such measures could include efficiency measures for example in the building sector as well as other incentives for the deployment of the most efficient technologies in order to reduce power consumption.

A short view on biomass potentials and their possibilities within the feed-in tariff framework shows a quite common phenomenon: There is a certain risk that increasing the production capacity of power (and heat) production from biomass takes too long due to time consuming procedures and necessary permits, especially for projects in the agricultural areas.

Technology	Ceiling in accordance with the Energy Act	Total potential built up (GWh)
Hydro power up to 10 MW	1655	2300
Biomass (without waste incineration plants)	600	3200
Geothermal energy	288	810
Wind energy	500	500
Photovoltaics	90	600
Waste incineration plants	900	900
TOTAL	4033	8310

Agricultural potentials – optimisation is the key word!

An important focus of the Swiss biomass strategy lies on the utilisation of the potentials from agriculture and forestry. According to our strategy residues and organic waste should be used in the first place. The cultivation of energy crops in a large scale is in our opinion not viable for Switzerland.

To a certain extent energy cropping could be an option to cover a niche at the most. Although the feed-in tariffs should per definitionem cover the costs, small scale plants will economically be less interesting. So our system should encourage the construction of plants of a reasonable size and operated in a sustainable way.

The most important aspects are the following:

- Biogas plants should have a certain size. At least a couple of farms should work together. They should implicate at least the region, the closest village and have to be constructed on adapted sites (for example close to a village, close to power or natural gas grids, etc.)
- Co-substrates from the industrial sector, service, tourist and / or household activities must partly cover the composting or fermentation process. They increase the efficiency of the system and optimize the production economically.
- Combined heat and power generation should be only allowed, if the efficiency of the whole system is on a high level, mostly by utilising and selling heat. The directive for biomass-generation in the feed-in-tariff system are quite clear: a minimal efficiency is the condition to benefit from the feed-in tariff for the renewable power.
- There must be a serious discussion on whether the available biomass is used for combined heat and power generation, for power generation only or for transport fuels. From an energetic point of view, biomass should mainly be used for combined heat and power generation. Regarding the transport sector efficiency measures should be implemented in the first place. In both cases the LCA has to be considered.

Of course the SwissEnergy programme supports indirect measures such as consulting, PR and so on. Unfortunately direct support of pilot and demonstration plants are not possible any more due to the lack of funds. However, there are private foundations such as Coop Naturaplan that are able to directly support certain projects. We estimate that till 2010 some fifty to hundred plants in the size of (150 to 300 kW installed power) should be realised.



Example: Biogas plant at Altshofen (LU, 2006)

Current knowledge on disease suppressive properties of composts

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Key words: Composts, biological control, biocontrol agents, plant disease, systemic induced resistance, ISR.

Abstract

Composts prepared from solid wastes with high concentrations of recalcitrant materials (bark, yard wastes, etc.) can be used effectively to suppress soilborne plant diseases but several factors must be controlled for optimum effects. Composts prepared from manures, especially those prepared from manure solids without bedding, are much less likely to provide these beneficial effects. The stability of the organic fraction in composts critically affects efficacy. The type of composting system used and the environment affects populations of biocontrol agents in composts. In practice, disease suppressive effects typically do not develop until after their utilization. Phytophthora, Pythium and Thielaviopsis root rots are suppressed most effectively by composts. This applies to container media as well as field soils. Inoculation of composts utilized in container media during the formulation process with specific biocontrol agents can increase the suppression spectrum to include diseases caused by sclerotium-producing pathogens such as Rhizoctonia solani. Inoculation with ISR-active biocontrol agents can further increase the suppression spectrum to include vascular wilts and foliar diseases. These diseases typically are not suppressed naturally by compost amendments. This paper presents an overview of historical perspectives and of recent findings in this field. ((codis-abstract))

Introduction

During the 1950's when chemical agriculture was in its "golden age", soils typically were tilled intensively while "organic wastes" were disposed off in landfills or applied at excessive nutrient loading rates on farmland. As a result, soil quality was poor and diseases caused by soilborne plant pathogens caused major losses even though it was understood that organic amendments could improve soil quality and plant health (Stone et al., 2004). Soils used for the production of trees and other woody ornamental plants at that time were of very low quality and suffered from erosion problems because the top soil was sold with harvested plants in root balls. Fumigants such as methyl bromide, nematocides and soil fungicides were used widely in this industry and this caused additional disruption of soil ecology and led to environmental pollution. In spite of these chemical treatments, Phytophthora root rot caused major losses on nursery crops. Breeding for resistance to these diseases was not a realistic option for woody plants even though this was a standard practice for agricultural crops (Hoitink and Fahy, 1986). Environmental problems caused by pesticides, excessive use of fertilizers and inappropriate disposal of organic wastes eventually produced legislation during 1971 that forced US agriculture to develop sustainable alternatives.

The nursery industry pioneered the return to more traditional soil management practices in two different ways. First, it began by replacing Sphagnum peat, which did not suppress Phytophthora root rots, with composted tree bark, which seemed to provide natural control of the disease. Thus, composted bark became a methyl bromide and soil fungicide alternative (Hoitink and Fahy, 1986). Unfortunately, plant growth often was variable from batch to batch in bark media. This was due to nitrogen deficiency in plants early after potting but also to imbalances of mineral nutrition and/or allelopathy problems caused by the bark from some tree species. Procedures were developed in several parts of the world for composting of bark from several different tree species that solved these plant growth issues (Hoitink and Fahy, 1986). In addition, bioassays were developed that compared the relative suppressive effects of potting mixes against diseases caused by several different types of plant pathogens. As a result of both types of efforts, compost-amended media became available that suppressed root rots caused by some *Phytophthora* and *Pythium* spp. and *Thielaviopsis basicola* (Fahy and Hoitink, 1986, Hoitink and Boehm, 1999). However, the bark-containing media did not consistently suppress diseases caused by *Rhizoctonia solani* or *Sclerotium rolfsii*. Vascular wilts and foliar diseases typically were not suppressed either (Stone et al., 2004).

The second move towards a return to more sustainable production practices in the nursery industry occurred during the early 1980's when composts prepared from municipal wastes and from manures became available as high quality soil amendments. Initially, leaf, bark, and sewage sludge composts

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were incorporated into ground beds at rates as high as 100 tons per ha. These composts were used as one time mulches or amendments to improve soil quality without causing pollution of ground or surface waters with nutrients. Follow up treatments used lower rates, based on soil type, soil quality indicators and crop requirements. These compost applications, in general, reduce the severity of Phytophthora, Pythium and Thielaviopsis root rots as long as several factors which include compost quality, soil fertility, timing of application, etc., are considered (De Ceuster and Hoitink, 1999). As observed earlier in container media, diseases caused by pathogens such as *Rhizoctonia* that produce sclerotia typically are not suppressed until several months after incorporation of the amendments into low quality, conducive to disease soils (Hoitink and Boehm, 1999, Stone et al., 2004).

To allow successful utilization, control must be exerted with respect to the raw materials used as feedstock, the composting process itself, the degree to which the compost has been stabilized during curing (i.e. maturity / stability), particle size, and finally, biological, chemical and physical properties of the product (De Ceuster and Hoitink 1999, Hoitink and Boehm, 1999). Composts that are most effective are those prepared from bark and woody residues, or created from animal wastes bulked with high in carbon material or straw. Least effective, and possibly problematic, are those prepared from post consumer food wastes, farm manures devoid of bedding (i.e. sawdust, stover or straw), both of which tend to be low in recalcitrant carbon. These less effective products also need to be applied in the fall to allow for leaching of salts if crops sensitive to Phytophthora or Pythium root rot are planted on the amended soil (De Ceuster, et al, 1998; De Clercq, et al., 2003; Stone et al, 2004). Thus, it is not surprising that composts do not consistently provided control of diseases caused by soilborne plant pathogens (Fuchs and Larby, 2005; Scheuerell et al., 2005; Termorshuizen et al., 2006).

Organic matter mediated biocontrol

The decomposition level (also referred to as maturity or stability) of the organic fraction in composts critically affects biological control (Hoitink and Boehm, 1999; Stone et al, 2004; Wang et al., 2006). Most vegetative and woody materials release glucose and/or other sugars early during their decomposition. These and other soluble nutrients support the growth of resident microbes, especially that of mycelium-producing plant pathogens. Although biocontrol agents such as *Trichoderma* reach high populations in such substrates, they initially do not suppress the pathogen due to glucose-induced repression of enzyme synthesis required for parasitism (Hoitink and Boehm, 1999). Antibiotics produced by some bacterial biocontrol agents also are affected in this manner (Duffy and Defago, 1999). To avoid problems associated with net pathogen stimulation by readily assimilable carbon, composts must be stabilized to a rate of respiration of no more than $1.0 \text{ mg CO}_2\text{-C g}^{-1} \text{ dw d}^{-1}$ (Wang et al., 2004) or they must be applied to field soil in the fall to decompose further in soil before planting of the crop in the spring.

The other end of the decomposition scale, which implies excessively stabilized or humified organic matter, typically does not support control either. For example, charred or pyrolyzed particles in composts do not support the levels of microbial biomass required to generally suppress root rots (Hoitink and Boehm, 1999). Charred particles are produced during composting when temperatures exceed 70°C for long periods of time, particularly when composts are dry. Maintenance of a moisture content $> 45\%$ and adjustment of windrow height (which affects the process temperature) during composting helps to prevent charring. Excessively humified organic matter, the other end of the decomposition spectrum, such as that in highly decomposed Sphagnum peat or as in composts after their mineralization in potting mixes for more than their "useful life time", does not support control either (Boehm and Hoitink, 1999; Stone et al, 2004). Thus, substrate chemistry matters and the microbial properties that lead to suppressiveness cannot be maintained indefinitely!

The longevity of the suppressive effect of composts depends on many factors. Stabilized lignocellulosic substances in composts, the chemistry of which resembles particulate organic matter (POM) in soil, seem to form the basis for long-term control (Stone et al., 2004). Generally, compost-amended container media become conducive to root rot within 12-24 month after potting, but this varies with the materials used and the climate. The rate of hydrolysis of fluorescein diacetate seems to best reflect this suppressive effect against root rots (Hoitink and Boehm, 1999; Stone et al, 2004).

Fate of biocontrol agents in composts

The microflora associated with the composting process includes organisms originating in the source material as well as those colonizing the piles during the composting process. Some of these can act directly as biocontrol agents, but it is thought that only heat-tolerant species, such as some *Bacillus* spp., will represent substrate-borne biocontrol inoculum (Hoitink and Boehm, 1999). The fate of this

microflora in high temperature composts seems similar to that of pathogens (Termorshuizen et al, 2005). While it is possible for other colonists to survive in the outer layers of stabilized piles, the moisture content in this layer often is too dry (< 45 % (w/w) for significant levels of growth. Thus, opportunities for colonization of such composts by biocontrol agents can be minimal. Biocontrol agents, mycorrhizae and nitrifying bacteria often do not colonize compost-amended substrates until days or weeks after the compost has been utilized (Hoitink and Boehm, 1999). This in practice means that potted crops highly sensitive to *Pythium* damping-off (e.g. poinsettia) must be drenched once with an effective *Pythium* fungicide immediately after planting to ensure damping-off control. Thereafter, natural suppression provides control (Hoitink, and Lewandowski, 2006).

The situation can be quite different for composting plants that use small windrows with low process temperatures, especially when a cover is used to mitigate drying during curing. After several years of operation on a site, composts produced in this manner can be expected to support higher populations of biocontrol agents in the cured product (Hoitink and Boehm 1999), including inoculants that can induce suppression to foliar diseases of plants (Horst et al, 2005). The turning machines used in these small windrow systems continually facilitate dissemination of microorganisms among windrows. Turning of mature compost first, followed by turning of fresh materials last, and a clean up operation before the next turning operation, is the best strategy. However, even with composts prepared by this method, formulated media do not naturally suppress *Pythium* diseases adequately until several days after planting. Thus, highly sensitive crops such as begonias must be drenched at planting with a *Pythium* fungicide for complete control (Horst et al, 2005, Hoitink and Lewandowski, 2006). Subsequent fungicide applications typically are not required until the medium loses suppressiveness towards the end of its useful lifespan. Another approach is to incubate biocontrol agent-fortified potting mixes for several days in storage so as to allow biocontrol agents to proliferate. This approach to disease control poses fewer risks for potted crops. In the large plant container industry, this approach typically is not practical due to the size of operations.

General disease suppression induced by composts

Compost effects on suppression have been related to amendment characteristics and soil type (Hoitink and Boehm, 1999).. Consistent and effective suppression of *Phytophthora* root rots provided by composts versus partial or lack of suppression of diseases caused by pathogens such as *Rhizoctonia solani* can be explained on the basis of the differences between the mechanisms that underly their suppression. Suppression of root infections by *Phytophthora* and *Pythium* is supported by microbiostasis which implies competition and antibiotic production by competing microorganisms (Baker and Paulitz, 1996). Numerous soil microorganisms contribute to this effect in soils. The general suppression phenomenon *sensu* Gerlach, which is soil carbon dependent, best explains this type of disease control provided by composts (Hoitink and Boehm, 1999). Other plant pathogens that produce small propagules (<200 U in diameter) seem to be suppressed by the same mechanism.

Recently, nucleic acid based techniques have been used to gain a better understanding of the microbial community structure and function in disease suppressive substrates (Kowalchuck et al., 2003; Mazzola, 2004; Benitez et al., 2007; Borneman and Becker, 2007). Using such approaches, very subtle shifts in community structure related to soilborne disease suppression can be observed in response to cropping history and rotation (Benitez et al 2007, Baysal et al 2008). Still, compost applications in the field have been shown to promote dramatic transient shifts in abundance, but not in the overall structure of native microbial communities (McSpadden Gardener et al 2002). This indicates that stimulation of general suppression is mediated by enhanced growth of the microflora present in the field. Such studies generally support conclusions from earlier work based on culturing of microorganisms but also reveal that an even greater abundance of microorganisms seems to play a role in disease suppression than realized previously.

Specific disease suppression induced by composts

Specific suppression refers to control of particular pathogens. It can be mediated by biocontrol inoculants. These specific biocontrol agents often act through multiple mechanisms, but it is becoming clear that those that induce plant host resistance can be particularly effective. This is because induced resistance in plants can be effective against several root, vascular and foliar diseases. Effective suppression of diseases caused by pathogens that produce sclerotia (e.g. *R. solani*) typically requires that biocontrol agents kill their infective propagules (Baker and Paulitz, 1996). This implies antibiosis and/or parasitism. Lack of consistent colonization of composts by such specific

microorganisms explains the inconsistent control of diseases caused by these pathogens (Hoitink and Boehm, 1999). Specific inoculants of biocontrol agents such as strains of *Trichoderma* spp. can be inoculated into compost-amended substrates to provide a more consistent degree of control (Hoitink and Boehm, 1999; Khan et al., 2003; Horst et al., 2005; Cotxarrera et al., 2002). For crops highly susceptible to *Rhizoctonia* damping-off such as New Guinea impatiens, a single fungicide sprinch (heavy spray) must be applied at planting to avoid losses. Introduced biocontrol agents do not provide adequate control on such crops unless the biocontrol agents can fully established themselves in the substrate (Hoitink and Lewandowski, 2006). Later in the cropping cycle, the biocontrol agent-fortified substrate can be more suppressive to *Rhizoctonia* root rot than the most effective fungicides.

A few reports show that foliar diseases of plants can be suppressed in compost-amended substrates (Stone et al, 2003, 2004). Bioassays performed with container media prepared from 1997-2001 with 80 different types of composted products, which included conventional, organic and vermicomposts, revealed that all suppressed *Pythium* damping off of cucumber, 20% suppressed *Rhizoctonia* damping-off of radish and only one induced systemic resistance (ISR) to foliar diseases naturally. Several different biocontrol agents with ISR activity were isolated from the unique batch of compost that naturally induced systemic resistance in plants. *Trichoderma hamatum* 382 (T382) was identified as the most active inducer of resistance (Krause et al, 2003). Other active isolates were *Bacillus* strains, and less active isolates included strains of *Pseudomonas* spp. and *Pantoea agglomerans*. Thus, the types of biocontrol agents isolated from the ISR-active batch of compost-amended mix agree with the spectrum of such isolates described from soil (Pieterse, et al, 2003; Soresh et al., 2005).

The foregoing reveals that suppression of foliar diseases with natural composts is a rare phenomenon in commercial practice. Thus, growers cannot rely on this approach to foliar disease control. This may explain why compost-induced foliar disease control was not discovered by growers under commercial conditions. The question is whether this deficiency can be remedied with controlled inoculants.

The mechanisms by which beneficial rhizosphere microorganisms induce systemic resistance in plants differ (Pieterse et al, 2003). The specific strains that induce ISR do not substantially activate PR protein synthesis before the pathogen invades the plant. The ethylene and jasmonic acid pathways are involved in this resistance mechanism (Pieterse et al., 2003; Soresh et al, 2005) but just how pathogen populations are suppressed in plants was not understood until recently. The ISR-active biocontrol agent *Trichoderma hamatum* 382 (T382) alters the expression of 45 genes in tomato (Alfano et al, 2007). The induced genes have functions associated with biotic or abiotic stress as well as RNA, DNA, and protein metabolism. Four extension and extension-like proteins in addition to PR 5 were induced. Extensin proteins have long been associated with defense mechanisms in plants (Shanmugam, 2005). Upregulation of a specific extension protein in *Arabidopsis* induced a high degree of resistance to bacterial spot in this plant (Wei and Shirsat, 2006). Thus, further work may show that an increase in extension gene expression by ISR-active biocontrol agents may well account for much of the systemic benefits associated with composts that provide foliar disease control.

Role of substrates in compost in ISR-activity

Amendment of peat mixes with composts has enhanced the systemic effect induced by ISR-active rhizosphere microorganisms in plants. Zhang et al., (1998) showed that dark, decomposed Sphagnum peat mixes do not induce ISR naturally. Suppression of *Fusarium* crown and root rot of tomato induced by the biocontrol agent *Pythium oligandrum* was enhanced by amending a Sphagnum peat mix with composted papermill sludge (Pharand et al., 2002). Furthermore, suppression of *Phytophthora* leaf blight of cucumber induced by *T. hamatum* 382 was enhanced by amendment of a peat mix with composted dairy manure. It increased resistance of the plant to the disease (Khan et al, 2004). Finally, greenhouse tests performed with T382 in a high in microbial carrying capacity light Sphagnum peat potting mix revealed that powdery mildew and *Botrytis* blight of begonia were suppressed as effectively as provided by bi-weekly foliar sprays with the fungicides piperon and clorothalonil, respectively (Horst et al, 2005). In conclusion, soil organic matter quality affects the activity of biocontrol agents that induce systemic resistance in plants as observed years ago for suppression of root rots (Heyl, 1999, Stone et al, 2004).

Is the degree of resistance induced by ISR useful to growers? ((codis-headline))

To answer this question, commercial scale demonstration trials were performed with T382 in nursery container media (Hoitink et al, 2006). In a trial with rooted cuttings of *Myrica pennsylvanica*, a severe outbreak of *Botryosphaeria* dieback caused by *Botryosphaeria dothidea* developed on the branches of

this woody plant. In the control medium, 20.8% of the plants were killed and only 25.0% of the plants remained symptomless. Most were stunted in growth. In contrast, only 6.3% of the plants in the T382-inoculated medium were killed whereas 66.7% of the plants remained symptomless. In conclusion, this control batch of natural compost-amended mix did not provide control of the dieback disease whereas the mix inoculated with T382 provided effective control of *Botryosphaeria* dieback, a disease for which effective fungicides are not available.

On *Rhododendron* "Roseum Elegans", a natural dieback epidemic caused by *Phytophthora citrophthora* developed (Hoitink et al., 2006). T382 significantly ($P=0.05$) reduced the severity of this disease. In a test with *Pieris japonica*, the percentage plants killed by *Phytophthora parasitica* was reduced by inoculation of the mix with T382 from 26 % in the treated to 4 % in the control. The reduction in *Phytophthora* dieback severity occurred in these tests even though the foliage of the crops had been treated repeatedly at three week intervals with Subdue and Aliette, systemic fungicides with activity against *Phytophthora*. In vitro analysis revealed that the *Phytophthora* isolates that caused these epidemics were resistant to 100 mg ml⁻¹ metalaxyl, the active ingredient in Subdue.

Recent work shows that efficacy induced by T382 against *Botrytis* blight of geranium is comparable to that provided by chemical fungicide under mild disease pressures which prevail under standard greenhouse conditions when growers vent houses to reduce the relative humidity. Under high moisture conditions, the fungicide was more effective and the biocontrol agent was not effective (Olson and Benson, 2007).

In conclusion, inoculation of container media which offer the potential to naturally suppress *Pythium* and *Phytophthora* root rots with ISR-active biocontrol agents such as T382 can significantly increase the spectrum of soilborne diseases suppressed and have an impact on control of foliar diseases as well. This holistic approach to disease control is particularly useful for powdery mildews and *Botrytis* blight under low disease pressures and for stress diseases such as those caused by *Botryosphaeria dothidea* because effective fungicides are not available for the latter. For control of damping-off diseases of highly susceptible floricultural crops, an initial fungicide treatment is required. However, the degree of protection provided by ISR against foliar diseases caused by aggressive *Phytophthora* species is limited. The best strategy against these diseases apart from clean stock production is to utilize irrigation strategies that minimize pathogen dissemination and leaf wetness periods in addition to fungicide applications (Hoitink and Lewandowski, 2006).

Future Outlook

Several new technologies developed during the past decade promise to significantly increase utilization of disease suppressive composts in the United States. A novel method for production of plants, known as the "pot-in-pot system", allows trees to be produced in containers buried in soil (Struve, 1996). In this system, the root system is protected from winter and high temperature summer impacts. Large trees can now be produced as effectively in these systems as in field soil. Furthermore, trees now can be produced in the absence of plant pathogens such as *Verticillium* spp. that survive as microsclerotia in infested soils even when treated with composts.

The pot-in-pot system is being adopted rapidly across the U.S. Therefore, the quantity of organic matter required for such systems is beginning to exceed the supply of composted bark and rice hulls. Thus, the nursery industry increasingly is testing alternatives for these basic ingredients in potting mixes. Composted yard wastes and other types of composts high in recalcitrant materials are beginning to fill this market but typically cannot be incorporated at rates that exceed 25% (v/v). Because pots used in these systems tend to be tall (30-60 cm) depending upon tree type and size, water retention and aeration requirements are different as well. Thus, larger quantities of composts that predominantly contain small particles can be utilized successfully in these media as long as nutrient levels do not exceed limits.

A second development which is a natural spin off from this new tree technology is "rapid production of nursery liners" from seed or rooted cuttings in disease suppressive systems. In this technology, liners of trees can be produced from seed into 1.5-2.0 m whips within one growing season. This avoids production of bare root field trees (whips) in pathogen or insect-infested soils and guarantees better products.

In a third development, the nursery industry incorporates composts and green manures between nursery crops into field soil on a 3-5 year production plan basis. Within three months after application of composted yard wastes or mixtures of composted bark and manures, a forest horizon develops in the treated soil. The dynamics of nutrient uptake and plant growth in such mulched systems resembles that in organic agriculture under the best conditions and in natural hardwood forest ecosystems. Root rots and feeding by leaf chewing insects are suppressed on such mulched trees

relative to in the fertilized non amended control (Lloyd et al., 2002). As long as yearly fertilizer inputs take into account crop fertility needs and the quantity of nutrients available to the plant in the soil and soil type, this approach to mulching does not lead to environmental insults. This still is a controversial topic, however, because our ability to predict N release from compost still is poor unless several factors for each specific compost type are considered.

It is too early to predict the role that microbial inoculants will play in enhancing disease control. However, based on impacts of recent epidemics caused by *Phytophthora ramorum* on nursery stock in the U.S., coupled with the desire of the industry to decrease pesticide use due to increased costs, re-entry regulations, and environmental issues for some pesticides, it would seem that ISR-active inoculants will increasingly be used by growers in the future. Indeed, the biopesticide industry has been expanding during the past five years to meet this perceived need with the development and registration of over two dozen new active ingredients that target soilborne diseases.

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Organic pollutants in compost and digestate: occurrence, fate and impacts

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Key words: Organic contaminants, Ecotoxicological assessment, Degradation, Composting, Digestion

Abstract

A yearly amount of 9.3×10^6 t compost and digestate derived from separately collected organic waste is produced in the 25 European Union member states. The improvement of soil properties is a major benefit of compost application. However, little is known about the occurrence of organic pollutants in compost. In the present study, polycyclic aromatic hydrocarbons (PAHs), ortho substituted and dioxin-like polychlorinated biphenyls (PCBs, DL PCBs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), perfluorinated alkyl substances (PFAS), pesticides, chlorinated paraffins (CPs), phthalates and nonylphenol (NP) were analyzed in samples from composting and digestion plants in Switzerland. All compound classes were detected except for NP. PFAS, HBCD, TBBPA, some compounds out of PBDEs and pesticides were found in compost and digestate for the first time. Concentrations of most compounds were in the low ppb range. Contents of PAHs were between 600 and 12473 $\mu\text{g}/\text{kg}$ dry weight (dw) and contents of HBCD and CPs between 17 and 384 $\mu\text{g}/\text{kg}$ dw. Degradation of PAHs and PCBs during composting and digestion was observed for PAHs with a low molecular weight only. Tests with springtails (*Folsomia candida*) have been shown to be a versatile tool for ecotoxicological assessment. Within these tests, inhibiting and stimulating effects due to compost application were observed. Except for high PAHs contents, no major problem with regard to contamination of compost and digestate was identified. However, it is necessary to thoroughly discuss among stakeholders the current state of the art with regard to contamination of compost and digestate in order to counterbalance potential risks of their application with their apparent and well-documented beneficial aspects and to guarantee for safe and sustainable recycling of separately collected organic waste.

Introduction

Composting of organic waste represents an important and well established part of waste management in Europe. In recent years, anaerobic treatment of organic waste materials and production of non-fossil energy have been promoted and thus, production of digestate and presswater (i.e. the products from liquid/solid separation of the fermenters output) has increased. About 9.3×10^6 t of compost and digestate are produced per year in the 25 European Union member states (Anonymous, 2005a). Composting and digestion of organic residues and application of compost to soils follow the principle of sustainability. Major benefits are the recycling of nutrients and the improvement of soil properties. Organic waste materials might contain pollutants that enter the soil by application of compost and digestate. The problem related to heavy metals has been recognized and investigated thoroughly (Plahl et al., 2002). However, little is known about organic pollutants. They can enter compost and digestate via atmospheric deposition or accidental (i.e. improper separation of input materials) and

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deliberate input (e.g. pesticide application) to organic materials. Data on feedstock materials and source-separated organic compost has recently been reviewed (Brändli et al., 2005). It was shown that information is sparse even for compounds included in the Stockholm Convention on persistent organic pollutants (POPs). Results on organic pollutants in digestate and presswater are not available. Additionally, emerging organic pollutants have not yet been systematically investigated in compost. They need to be included in the studies, since they have reached comparable production volumes and exhibit similar properties as the well known POPs, i.e. ubiquitous occurrence, toxicity, persistence, and/or endocrine disrupting effects (Jones and de Voogt, 1999). In order to thoroughly evaluate impacts from compost application, chemical studies have to be combined with investigations on effects of compounds. For topics such as evaluation of new pesticides, ecotoxicological tests using soil invertebrates have become well established methods for studying impacts (Fountain and Hopkin, 2005). Ecotoxicological tests for compost application have been proposed recently by Kapanen and Itavaara (2001). For this topic, organisms are exposed to compost-soil mixtures and the pollutants incorporated in compost, respectively.

In order to guarantee for safe and sustainable recycling of source-separated organic waste by aerobic and anaerobic treatment the gaps of knowledge with regard to the transfer of organic pollutants to soil and their impacts have to be filled. Therefore, the present study was carried out with the following aims: determination of (i) the concentrations of organic pollutants in compost and digestate, (ii) the parameters driving concentrations, (iii) fate and degradation of organic pollutants during composting and digestion and (iv) impacts of organic pollutants in compost and digestate to soil organisms. Within this investigation, a monitoring study on organic pollutants in compost and digestates, a study on degradation of organic pollutants during composting and digestion in full-scale plants and an ecotoxicological assessment on the basis of laboratory tests were performed. In parallel to the present study, an investigation on beneficial aspects with regard to application of compost and digestate was performed (Fuchs et al., 2004). Most of the samples analyzed were included in both studies.

Materials and methods

Monitoring study

- Experimental design

Samples of compost or digestate derived from source-separated organic waste were collected from 32 commercial composting and 7 digestion plants in Switzerland. The process technology used by the plants was open windrow composting (triangle windrows: n= 19; table windrows: n=3), thermophilic digestion (n=6), combined digestion and composting (n=5), aerated boxes (n=3), aerated trenches (n=2), mesophilic digestion and vermicomposting (n=1 each). The experimental design accounted for the factors hypothesized to drive the level of pollutants in compost and digestate (Brändli et al., 2005): (i) treatment process: aerobic and anaerobic treatment with compost and digestate/presswater as resulting products. Note that most of the digestates underwent subsequent aerobic treatment. (ii) feedstock materials: The quantitatively most important materials are kitchen waste (crude organic waste originating from private kitchens) and green waste (organic waste from private gardens and public green areas) (Hügi and Kettler, 2004). Note that compost containing kitchen waste was always derived from a mixture of kitchen waste and green waste. All of the digestates contained kitchen waste. Other organic residues originating from industry, agriculture or from maintenance of roadsides were included in some of the composts and digestates. Paper and cardboard were not allowed as feedstock materials. (iii) origin of the feedstock materials: urban, rural. (iv) season of input material collection: spring/summer, autumn, winter.

These factors were assessed by nonparametric statistical tests (Brändli et al., 2007a,b). These tests do not require normal distribution of the data and are robust to outliers.

- Compounds analyzed

The compounds analyzed within the monitoring study, their main applications and the number of samples analyzed are given in tab 1. The analytical methods are described in Brändli et al. (2006, 2007a).

Tab. 1. Compounds analyzed within the monitoring study (abbreviations used throughout the text in bold letters), their main applications and the number of analyzed samples

	Source/Application	n _(s) *	n _(p) *
Polycyclic aromatic hydrocarbons, PAHs (sum of 15 PAHs ⁱ⁾ : naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene)	Fuel, combustion (heating, power plants, waste incineration plants), open fires, motorized road traffic (vehicle exhaust, abrasion of asphalt and tires)	85	39
Ortho substituted polychlorinated biphenyls, PCBs (sum of 7 congeners 28, 52, 101, 118, 138, 153, 180) ⁱⁱ⁾	Oil in transformers, dielectrics in capacitors, hydraulic fluids, lubricants, plasticizers; banned since the 1970s	85	39
Dioxin-like polychlorinated biphenyls, DL PCBs (sum of congeners 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189) ⁱⁱ⁾		20	12
Polychlorinated dibenzo- <i>p</i> -dioxins and -furans, PCDD/Fs ^{ii), iii)}	Combustion	20	12
Polybrominated diphenyl ethers, PBDEs , pentaBDE ^{iv)} , DecaBDE (i.e. congeners 28, 47, 99, 100, 153, 154, 183, 209)	Flame retardants (plastics, textiles, materials for vehicles and construction, electric and	20	12
Hexabromocyclododecane, HBCD	electronical equipment)	20	12
Tetrabromobisphenol A, TBBPA		20	12
Perfluorinated alkyl substances, PFAS : sum of 6:2 fluorotelomer sulfonate and saturated/unsaturated fluorotelomer carboxylates, 6:2 FTS/FT(U)CA ; sum of perfluorinated sulfonates, PFS ; sum of perfluorinated carboxylates, PFCA ; sum of fluorooctane sulfonamides and -sulfonamidoethanols, FOSA/FOSE ⁱⁱⁱ⁾	Stain and water repellents for surface treatment of textiles, carpets, leather and paper products, fire fighting foams, lubricants, insecticides	18	11
Pesticides: sum of 271 compounds, i.e. 86 fungicides, 86 herbicides, 92 insecticides, 5 acaricides, 1 nematocide, 1 plant growth regulator ⁱⁱⁱ⁾	Plant protection, material protection	18	11
Chlorinated paraffins, CPs (sum of short chain (C ₁₀ -C ₁₃) and medium chain (C ₁₄ -C ₁₇) chlorinated paraffins) ^{iv)}	Metal working fluids, paints, coatings, sealants, flame retardants, plasticizers	3	3
Phthalates: di-2-ethylhexyl phthalate, DEHP ; dibutylphthalate, DBP	Plasticizers	6	6
Nonylphenol, NP	Metabolite of nonylphenolpolyethoxylates ^{v)} , used as flotation, dispersing and emulsifying agents (e.g. in pesticides)	6	6

* n_(s): number of samples analyzed, n_(p): number of composting or digestion plants investigated

ⁱ⁾ Usually, the sum of 16 EPA priority PAHs including dibenz[a,h]anthracene is reported. Due to difficulties for quantification of this compound, the sum of 15 PAHs is reported (dibenz[a,h]anthracene usually accounts for 1 – 2 % of Σ 16 EPA PAHs)

ⁱⁱ⁾ Compound included in the Stockholm Convention on persistent organic pollutants (POPs)

ⁱⁱⁱ⁾ A complete list of the single compounds analyzed is given in Brändli et al. (2007a)

^{iv)} Restricted applications in the EU

^{v)} Restricted applications in the EU for detergents

- Study on degradation of PAHs and PCBs during composting and digestion

Degradation of PAHs and PCBs during composting and digestion was investigated in two open windrow composting plants and on a thermophilic digestion plant. On the digestion plant, the input material (source-separated organic waste, presswater and digestate used as inoculum) and, according to the residence time in the fermenter of 12 days, the output was sampled (digestate and presswater). The digestate was subsequently composted on open windrows. On the composting plants, sampling was as follows: day 0 (input material), and day 3, 7, 14, 28, 56 and 112 (Brändli et al., 2007c).

- Ecotoxicological assessment

An ecotoxicological assessment was carried out on the basis of tests using collembola, commonly known as springtails (*Folsomia candida*). They are an integral part of the soil ecosystem and occur in soils throughout the world. *Folsomia candida* exhibit a short reproductive cycle and are easy to maintain in the laboratory (Fountain and Hopkin, 2005). Within the test, the survival and reproduction rates of springtails were evaluated after 28 days of exposure to compost mixed with an arable soil at a ratio of 1:7.5 (corresponding to an application rate of 100 t dw (dry weight)/ha incorporated in the top 5cm of the soil layer). The observed effects were compared to the control (i.e. arable soil used for the soil-compost mixture). A subset of 18 samples analyzed within the monitoring study was investigated (Pohl et al., in preparation).

Results and discussion

Monitoring study

All compound classes investigated were detected except for nonylphenol (NP). Concentrations were in the range of $\mu\text{g}/\text{kg dw}$ for most of the substances (Tab. 2). Polycyclic aromatic hydrocarbons (PAHs) showed contents between 600 and 12473 $\mu\text{g}/\text{kg dw}$. Approximately 25 % of the samples exceeded the guide value defined in the Swiss ordinance on the reductions of risks linked to chemical products (Anonymous, 2005b). The contamination level for PAHs was higher as compared to values available from the literature (Brändli et al., 2005). Concentrations of ortho substituted polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-*p*-dioxins and -furans (PCDD/Fs) were lower compared to former analytical results (Brändli et al., 2005). This might reflect declining environmental concentrations for PCBs due to their ban in the 1970ies (Sweetman and Jones, 2000). The decrease of PCDD/Fs has been observed for other matrices such as sewage sludge as well (Rappe et al., 1997) and is mainly due to measures taken in waste incineration and industrial activities. Concentrations of phthalates were in the same range as levels observed in other studies (Brändli et al., 2005). Hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), perfluorinated alkyl substances (PFAS), decaBDE among polybrominated diphenyl ethers (PBDEs) and several emerging pesticides (e.g. triazoles) were detected in compost and digestate for the first time. The concentrations were in the low ppb range except for HBCD and chlorinated paraffins (CPs) which showed contents between 17 and 384 $\mu\text{g}/\text{kg dw}$. It is not surprising that these compounds were found in compost and digestate since they belong to high production chemicals and are incorporated in a vast number of products for daily use or, as for pesticides, they are directly applied onto agricultural products that end up in organic waste.

For PAHs, PCBs, PCDD/Fs and PBDEs, concentrations determined in compost and digestate were above levels found in arable soils or grassland (Bucheli et al., 2004; Schmid et al., 2005; Sellström et al., 2006). DEHP showed higher levels in soil than in compost (Langenkamp and Part, 2001). In urban areas or at contaminated sites, levels of organic pollutants in soil can be in the same range or considerably higher compared to contents in compost.

Digestate tended to exhibit higher concentrations as compared to compost except for PCDD/Fs, PCBs and PFAS. Except for PAHs, the differences were not statistically significant however. Presswater showed contents in the same range as digestate except for HBCD. Compost from urban areas exhibited higher concentrations of PCBs (statistically significant difference). For PAHs, no corresponding difference was observed. In urban areas, composts are preferentially susceptible for contamination due to higher burdens of pollutants as compared to rural sites. A major input pathway to organic feedstock materials is likely to be atmospheric deposition. For PAHs, motorized road traffic might be another important source. However, this point was not thoroughly investigated within this study.

Compost containing kitchen waste showed slightly lower contents of PCBs compared to green waste compost (statistically significant difference for 3 congeners). For PAHs, no significant difference was observed. It can be hypothesized that organic waste collected in private households exhibits higher concentrations of organic pollutants than green waste due to higher contents of impurities resulting in elevated contamination levels (Brändli et al., 2005). This was not confirmed by the results of this study. Statistical analysis of the dataset as well as determination of impurities contents did not correlate with the concentrations of pollutants.

In general, PAH concentrations were highest in compost derived from input material collected in spring/summer, decreased in winter and were lowest in autumn. This is not in line with emission data which was higher in winter than in summer (Schauer et al., 2003), but it was found before that contents in compost were highest in seasons with low emissions (Brändli et al., 2005) indicating a certain lag phase between emission and input material collection. Additionally, the composition of input materials varies over the year which might play a certain role for contamination of the resulting composts as well.

Tab. 2 Concentrations in Swiss compost, digestate and presswater in µg/kg dw except for dl-PCBs given as ng WHO-TEQ/kg dw and PCDD/Fs given as ng I-TEQ (TEQ: toxicological equivalents); n: number of samples analyzed

	Compost*				Digestate**				Presswater			
	Mean	Med	Range	n	Mean	Med	Range	n	Mean	Med	Range	n
PAHs	3098	2750	600-10047	56	5925	4202	2337-12473	13	6565	5780	5445-9310	5
PCBs	30	25	9-102	55	32	31	20-52	13	26	25	21-35	5
DL PCBs	3.1	2.7	0.4-6.3	13	4.1	3.7	2.4-6.8	5	4.2	4.2	3.1-5.3	2
PCDD/Fs	5.6	4.0	0.5-21.0	13	3.2	2.7	1.3-6.6	5	6.1	6.1	3.8-8.5	2
pentaBDE	2.1	1.9	0.2-3.6	13	2.7	1.9	1.2-4.9	5	2.0	2.0	1.5-2.5	2
octaBDE	0.4	0.2	0.1-3.6	13	0.3	0.3	0.2-0.5	5	0.3	0.3	0.2-0.4	2
decaBDE	7.0	6.9	0.6-13.9	13	13.8	10.0	1.7-30.8	5	12.8	12.8	7.0-18.5	2
HBCD	83	47	17-234	13	187	174	98-372	5	43	43	30-56	2
TBBPA	0.6	0.5	0.1-2.3	13	0.9	1.0	0.4-1.5	5	1.6	1.6	1.0-2.3	2
6:2FTS/FT(U)CA	1.2	1.4	0.4-1.5 ⁱ⁾	13	0.2	0.0	nd-0.9 ⁱⁱ⁾	5	-	-	-	-
PFS	4.3	2.2	1.0-23.6	13	3.9	2.3	2.0-8.6	5	-	-	-	-
PFCA	3.5	2.2	1.3-9.9	13	4.1	3.1	2.4-6.6	5	-	-	-	-
FOSA/FOSE	0.1	0.2	0.0-0.3 ⁱⁱⁱ⁾	13	0.3	0.3	0.2-0.4 ^{iv)}	5	-	-	-	-
Pesticides	54	39	17-160	13	114	78	28-251	5	-	-	-	-
CPs	242	194	142-384	3	-	-	-	-	-	-	-	-
DEHP	240	212	145-395	4	1140	1140	295-1985	2	-	-	-	-
DBP	nd ^{v)}	nd	nd	4	nd	nd	nd-105	2	-	-	-	-
NP	nd	nd	nd	4	nd	nd	nd	2	-	-	-	-

* Composts containing important amounts of feedstock materials other than kitchen or green waste (e.g. farmyard manure) were excluded from statistical evaluation. Results of these samples:

PAHs (n=8): median: 978 µg/dw (range: 625-2954 µg/dw); PCBs (n=9): median: 16 µg/dw (range: 6-536 µg/dw)

** Products from thermophilic digestion. Results for products from mesophilic digestion (n=3):

PAHs: median: 2314 µg/dw (range: 947-3784 µg/dw); PCBs: median: 10 µg/dw (range: 6-74 µg/dw)

ⁱ⁾ detected in 7 samples; ⁱⁱ⁾ detected in 2 samples; ⁱⁱⁱ⁾ detected in 7 samples; ^{iv)} detected in 4 samples, ^{v)} nd: not detected

Among the pesticides, 20 % of the compounds analyzed were detected with fungicides as dominating compounds. Highest median concentrations were found for imazalil (9.0 µg/kg dw; detected in 14 out of 18 samples) and thiabendazole (5.3 µg/kg; detected in 13 out of 18 samples). They are used for post-harvest treatment of citrus fruit where residues are frequently detected (Taube et al., 2002). Among the fungicides, triazoles (e.g. difenoconazole, fenbuconazole, propiconazole, tebuconazole) were dominating in terms of frequency of occurrence with contents in the low ppb range.

Study on degradation of PAHs and PCBs during composting and digestion

Overall, the field study did not seem to result in important degradation rates of PCBs for both composting and digestion (Brändli et al., 2007c). The results of chiral analysis of PCBs were in line with these findings (Bucheli and Brändli, 2006). Removal was observed for PAHs with a low molecular weight which coincides with earlier studies (e.g. Hund et al., 1999).

Ecotoxicological assessment

Within the ecotoxicological assessment, 16 samples showed inhibiting and 13 samples stimulating effects with regard to the reproduction of springtails *Folsomia candida* (Pohl et al., in preparation). The effects were statistically significant for 4 and 5 samples, respectively. Mortality of adult springtails higher than 20 % was found for 14 samples (for 3 statistically significant). Reproduction was not related to adult survival. It was not possible to identify substances responsible for the observed impacts of compost on reproduction and mortality since the effects were not correlated with the concentration of pollutants.

The classification scheme for the evaluation of toxicity defined for soil according to Achazi et al. (2000) was applied to compost. Four samples were considered as low toxic, the others were not toxic or even stimulating. These findings are in accordance with a risk assessment on compost application carried out previously within the present study (Aldrich and Daniel, 2003) and field or laboratory investigations which found positive effects for springtails (Petersen et al., 2003) and other soil organisms (Hund et al., 1999) due to organic matter originating from compost or sewage sludge application.

Stimulatory effects of low-doses of pollutants have been reported in the literature (e.g. Erstfeld and Snow-Ashbrook, 1999). It is not yet clear, whether this might be an indication of stress. Moreover, adverse effects of mixtures of pollutants and their metabolites present at low concentrations were observed (Junghans et al., 2006). However, little is known on these topics for terrestrial ecosystems.

Conclusions

This study provides a comprehensive overview on organic pollutants in source-separated compost and digestate. To our knowledge, it is the first time that compounds such as PFAS, HBCD, TBBPA, decaBDEs and some emerging pesticides were analysed in compost. Moreover, digestate and presswater have not been included in a monitoring study on organic pollutants before. Most of the compounds could be quantified in the range of $\mu\text{g}/\text{kg dw}$. The concentrations were equal or above concentrations found in arable soil, the main recipient of these organic waste products.

Highly toxic effects were not found among the 18 samples tested within cotoxicological tests. This is in line with the literature based ecotoxicological risk assessment carried out by Aldrich and Daniel (2003). Within field studies, adverse effects due to application of compost or sewage sludge were not observed or to a minor degree only (Bartl et al., 2002; Traulsen et al., 1997). Even when considering results from a recent risk assessment which included organic pollutants, it seems that there is no need to exclude recycling fertilizers from land application (Klages and Roth, 2001). However, large gaps of knowledge with regard to analytical and ecotoxicological aspects were pointed out (Aldrich and Daniel, 2003). Such gaps were filled within the present study to a certain extent. Therefore, it is suggested to launch the discussion on the sustainability of organic waste recycling and application of the resulting products to soils among stakeholders (e.g. environmental and soil scientists, producers of compost, decision makers from authorities and associations, consultants, non-profit organisations etc.) considering the actual state of the art. This process aims at identifying future topics within this domain such as:

- Determination of sources of organic pollutants in compost and digestate. New issues might arise from co-digestion of organic wastes with farmyard manure in mesophilic digestion plants since new waste products are expected to be introduced in these facilities,
- Monitoring the trends of pollutants concentrations in compost and digestate (e.g. once in five or ten years) on a selected number of facilities,
- Investigation of the spatial distribution of compost on agricultural surfaces,
- Monitoring of concentration trends, investigation of availability and long-term fate of organic pollutants in soils fertilized with compost, digestate or presswater,
- Investigation of effects induced by mixtures of pollutants and their metabolites to soil organisms.

Further investigations on these topics might contribute to improve the environmental safety with respect to recycling of source-separated organic waste and thus, to better establish the products derived thereof within sustainable land use systems.

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Session 2.1:
Aspects of compost quality

Humic acids – A quality criterion for composts

Erwin Binner¹, Johannes Tintner¹, Katharina Meissl¹, Ena Smidt¹, Peter Lechner¹

Key words: compost quality, humic substance, humic acids

Abstract

In Europe humic substances are discussed as parameters describing the quality of composts. 10 years ago ABF-BOKU started to analyse humic acids - an extractable part of the humic substance - to assess the quality of composting processes and the final product. Therefore we use a photometric method according to DANNEBERG and SCHAFFER (1974). Laboratory tests, field tests and analysis of 132 different composts showed the main influences for the development of humic acids. Different feedstock (biowaste, yardwaste, sewage sludge), additives (minerals, lignines) and conditions during processing (strict aerobic, anaerobic/aerobic) were tested.

Introduction

Nowadays in almost all European countries the quality of composts is defined by low contents of pollutants (heavy metals, organic pollutants, impurities). Furthermore other parameters, describing the “real” quality of composts (benefits by application, stability of organic matter) are needed. Humic substances are discussed as parameters describing the quality of composts.

10 years ago the ABF-BOKU started to analyse humic acids - an extractable part of the humic substance - to assess the quality of composting processes and the final product. 2005 to 2007 a research program investigates impacts for better humification during composting of bio waste.

Materials and methods

132 different composts and samples from various composting processes from full scale plants (open windrow systems and in vessel systems) and from laboratory tests were analysed. Laboratory tests were done in a climate chamber with 2 different systems: forced aerated rotting reactors (7 l, they were used to adjust the temperature of the climate chamber) and natural aerated cups (200 ml). Parallel tests in cups and full scale plants showed, that over a 4 weeks period the laboratory system represents the full scale variant very well. The big advantage of the small system is the possibility to test a high number of variants at once.

Conventional parameters like LOI, TOC, C/N-ratio and respiration activity were analysed. A special focus was set on new analytic methods describing compost quality and the degree of maturity like extractable humic substances (according to DANNEBERG and SCHAFFER, 1974), FTIR-analysis (Fourier Transform InfraRed Spectroscopy) and TG-MS-analysis (Thermo Gravimetry – Mass Spectroscopy). The correlation of the results of these different methods with conventional parameters was checked. Results will be presented by Katharina Meissl (2008).

Method for analysing humic acids: Air dried compost samples were ground by vibratory disc mill and sieved to a particle size < 0.63 mm. 10 g of the laboratory sample were diluted with 50 ml sodium pyrophosphate (SPP) over night. The extract is separated from the solid residues by centrifugation (15 minutes, 13,500 rpm). The supernatant is filled into a 100 ml measuring flask (glass). Distilled water is added up to 100 ml (= unfractionated extract).

For determination of the Fulvic Acid (FA) fraction, 25 ml of this unfractionated extract are mixed with 0.3 ml 37 % HCl (pH < 2). After centrifugation (5 minutes, 7000 rpm) the supernatant is filled in a 50 ml measuring flask. Since the optical density is determined at the pH value of 10, 0.5 ml (0.6 ml) NaOH (40%) are added. Fulvic Acid fraction is determined by photometer at 400 nm. The Brown Humic Acid fraction is determined by subtraction of the optical density of the unfractionated extract fraction minus the optical density of the FA fraction.

The extraction and determination procedure for each sample is repeated on 4 days.

For quantification (to get result in % oDM) a calibration (for whole test-series) or a gravimetric evaluation of the precipitated Humic Acids is to be done.

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Conclusions

Laboratory tests, field tests and analysis of 132 different composts showed the main influences for the development of humic acids. The feedstock for the composting process has to contain components well-balanced from scarcely to easily available material (kitchen wastes + yard wastes). Pure sewage sludge or sewage sludge with low amount of yard wastes lead to a low development of humic acids.

Lignin and mineral additives may enhance compost quality. But first tests showed inconsistent results. One type of lignin and carbonate additive showed positive effects whereas other lignins and minerals did not confirm these results. Further investigations are to be done.

For processing, natural aerated windrow systems as well as reactor systems are suitable to produce high quality compost (fig. 1). Optimising mineralisation by very intensive oxygen supply leads to very low development of humic acids. By this quick mineralisation metabolic products of degradation will be decomposed completely by microbes or discharged by the waste air. Important for high compost quality is an unhurried degradation with long lasting biological reactivity of the feedstock, whereby microbes have enough time to use metabolic products for humic acid formation. Anaerobic pre-treatment seems to be positive for the development of humic acids during the following rotting period. We think that once more the low speed of degradation and the metabolic products produced by anaerobic microbes are responsible for that.

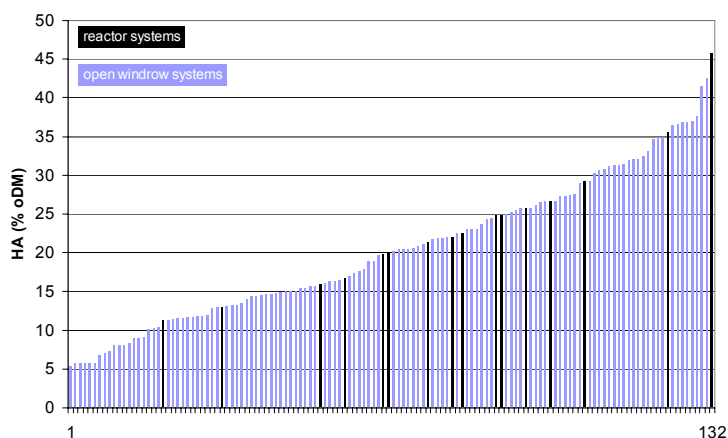


Figure 1: 132 different materials arranged according to their content of humic acids (% oDM). The materials gained from closed systems are marked lighter

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A new analytical approach to determine compost quality

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Key words: compost quality, analytical tools, Fourier Transform Infrared (FTIR) spectroscopy, Thermal analysis, multivariate data analysis

Abstract

Humic acids are a stable fraction of organic matter in soils. The positive effects of humic acids on plants and soil are well known. The different analytical procedures for humic substances determination are time consuming and expensive. Thus, other methods such as Fourier Transform Infrared (FTIR) Spectroscopy and Simultaneous Thermal Analysis were applied. In combination with multivariate data analysis analytical tools for practical application were developed.

Introduction

Analytical methods play a crucial role in process- and quality control of composts. Organic matter in composts is usually characterized by means of sum parameters, e.g. loss on ignition, total organic carbon, nitrogen. New analytical tools provide more information on compost features. The definition of quality criteria is a prerequisite for marketable products.

Humic acids are a stable fraction of organic matter in soils. Due to the well known favorable effects of humic acids on plants and soils they represent a suitable parameter to determine the quality of compost organic matter. Different analytical procedures are available to determine humic substances in soils and composts. These analyses are very time consuming and expensive. Thus, other methods that are widely used in many industrial processes for quality control were transferred to compost quality assessment. Fourier Transform Infrared (FTIR) Spectroscopy and Simultaneous Thermal Analysis (Thermogravimetry TG and Differential Scanning Calorimetry DSC) are promising tools in compost quality assessment.

Materials and methods

Humic substances were extracted using a 0.1 molar solution of sodium pyrophosphate (pH 10.5). Different fractions were separated according to their solubility in acidic or alkaline solutions according to Danneberg's procedure (modified) as described by Gerzabek et al. (1993). Their optical densities were measured photometrically at 400 nm.

Infrared spectroscopic investigations were carried out in the KBr technique. Two mg of the sample were mixed with 200 mg KBr (FTIR grade) and pressed to a pellet. The pellet was measured using a Bruker Equinox 55 under ambient conditions in the transmission mode. Parameters for infrared measurements: mid-infrared range (wavenumber 4000 - 400 cm^{-1}); resolution: 4 cm^{-1} , average of 32 scans for each spectrum corrected against ambient air as background.

Thermal analyses were performed using an STA 409 CD Skimmer (Netzsch GmbH) to enable the recording of thermograms and DSC-curves simultaneously. All samples were combusted with oxygen/helium (gas flow: 150 ml min^{-1} containing 20 % of oxygen and 80 % of helium) within a temperature range from 30 to 950 °C. The heating rate was set to 10 K min^{-1} , sample weight: 5.00 mg.

Results

Infrared spectra, thermal profiles and enthalpies shed light on the chemical composition and physical properties of the material (Smidt and Schwanninger, 2005; Smidt and Lechner, 2005). Chemical features and thermal behavior which are reflected by the spectroscopic and thermal pattern change during biological processes. These characteristics are the basis for the identification of stable and mature products with high content of humic acids. These methods provide many data points for one sample. For data evaluation multivariate data analysis is useful. Multivariate data analysis allows the extraction of additional information from such huge data pools generated by spectroscopic or thermal analyses. Based on a mathematical procedure the structure of data pools is revealed and can be applied for a specific purpose. By means of multivariate data analysis different evaluation tools of compost quality are available. These analytical tools are promising for practical application. One of these analytical tools is the humic acid prediction model by means of FTIR spectra developed by

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Meissl et al. (2007). Several spectral regions are highly correlated with the humic acid content measured according to Danneberg's procedure (Gerzabek et al., 1993). Humic acid content determination is less time consuming using the prediction model because an infrared spectrum is obtained within 15 minutes compared to a four days extraction procedure.

Many other problems in composting practice can be answered as well by these analytical tools combined with multivariate data analysis. The assignment of composts to defined quality criteria might be a relevant issue. Classification models enable to distinguish different kinds of composts according to the treated input materials (biowaste, yard waste, leftovers, sewage sludge), to process operation (aerobic / anaerobic) and to degradation stages (immature / mature) due to their specific spectroscopic or thermal pattern. Classification of waste materials using FTIR-spectroscopy was performed by Smidt et al. (2007). The decision whether the compost complies with a defined class or does not can be verified by discrimination analysis. The definition of the different classes is an important point. Smidt et al. (2007) defined the class "biowaste composts" only by end products of biowaste that underwent an aerobic treatment.

Thermal analysis can be used to distinguish sewage sludge composts (Smidt and Tintner, 2007). Smidt and Tintner (2007) reported that sewage sludge composts show different characteristics to biowaste composts in differential scanning calorimetry (DSC) profiles.

Conclusions

Infrared Spectroscopy and Thermal Analysis are innovative analytical methods used for compost quality assessment. Analytical tools such as humic acid prediction from FTIR spectra and compost classification were established by Meissl et al. (2007) and Smidt et al. (2007). Due to the easy handling, the reliability and fast evaluation the analytical tools presented in this paper are promising for practical application. Evaluation tools for thermal analysis are developed currently.

Acknowledgments

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Nitrogen – A harmful or a value-added compost property?

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Key words: nitrogen types, composting, nitrogen contents and emissions, fertilization, environmental pollution

Abstract

The behaviour of nitrogen (N) was studied in 53 technical scale composting experiments. The chemical characteristics of the composts regarding organic N (N_{org}), ammonium/ammonia-N (NH_4^+/NH_3 -N), nitrate-N (NO_3^- -N) and nitrite-N (NO_2^- -N) were determined at the different stages of composting. The NH_3 and N_2 released with the exhaust gas as well as the leached N provided cumulative values for the whole composting process. The results were evaluated regarding the value-added and the harmful potential of the specific N-compounds. Based on the results, the range of lost reactive and inactive N as well as the range of N-compounds with a fertilizer value was quantified in a broad manner for composting.

Introduction

The global N cycle is unstable. The N involved in composting may have positive or negative impacts on this cycle. On one hand, the N contained in compost may be important as a fertilizer, on the other, harmful impacts can be attributed to N-compounds which may be generated during composting or during compost application. These include the following impacts: plant-available N can cause water eutrophication; NH_3 in water may be toxic to fish; NO_3^- / NO_2^- in drinking water may be toxic / carcinogenic to humans; NH_3 in air may be malodorous and easily attaches to particulate matter; over-fertilization in certain habitats (e.g. forests) can occur after the deposition of NH_3 ; N_2O contributes to the degradation of the stratospheric O_3 layer making it one of the most important greenhouse gases; NO_x contributes to the formation of toxic O_3 in close-to-ground atmospheric layers; transformations into HNO_3 may lead to acid rain (Martinez et al., 2007; Körner, 2008).

Materials and methods

The N-turnovers and releases during composting were studied in 53 experiments by establishing N-balances. The test set-up of the technical scale composting plant using 100 l bioreactors as well as the measurement techniques and the analytical methods used are described in Körner (2008). Real waste (biowaste, digestion residues, MSW, chicken excrement, vegetable waste, sewage sludge) and a well defined model waste (consisting of 7 – 10 of the following components: apples, potatoes, turnips, wheat, peas, meat and bone meal, wood, bark, straw, leaves, grass, sand) were used. The process control parameters consisting of aeration rates, temperature profiles, water contents, portion of structural material and pH values were varied. In this publication, the contents of the different N-compounds in the compost (N_{org} , NH_4^+/NH_3 -N, NO_3^- -N, NO_2^- -N) were evaluated for the different composting stages (Phase 1: Stage with maximum temperatures; Phase 2: Stage with decreasing temperatures; Phase 3: First month of maturation stage; Phase 4-7: all stages between 1 and 17 months maturation). The N-emissions were given as cumulative values for the whole composting process. Despite the different composting durations, the different experiments were comparable regarding N-emissions since no more quantitatively significant N-releases occurred during the maturation phases. The following N-emissions were considered in this publication: the NH_3 emissions in the exhaust gas and the leached N were measured. The N_2 releases into the exhaust gas were determined indirectly using a method based on N-balances (Körner, 2008). The values for N_2 releases should only be considered as approximate. Information on the release of N_2O and NO_x were not considered in this publication, but can be found in Körner (2008).

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Results

The N-compounds which were detected in the different composting stages are presented in Tab. 1. The detection limit for $\text{NH}_4^+/\text{NH}_3\text{-N}$ in the compost was 0.1 kg N/ Mg dm; for both $\text{NO}_3^- \text{-N}$ and $\text{NO}_2^- \text{-N}$ the value was 0.001 kg N/ Mg dm (dm: dry matter). The N-compounds released during composting are given in Tab. 2. The minimum and maximum values should be considered with caution. Inhomogenities in the samples in particular may lead to high uncertainties (Körner, 2008). The probability is high that extreme values are under or over estimated. To avoid misinterpretation, only the 25%-75% quantile values were considered for evaluation.

Tab. 1: Chemical characteristics of the composts in different composting phases.

Parameter	Composting Phase 1		Composting Phase 2		Composting Phase 3		Composting Phase 4-7	
	n_{det} (n_{an})*	25%-quantile; median; 75%- quantile (minimum; maximum)** [kg N / Mg dm]	n_{det} (n_{an})*	25%-quantile; median; 75%- quantile (minimum; maximum)** [kg N / Mg dm]	n_{det} (n_{an})*	25%-quantile; median; 75%- quantile (minimum; maximum)** [kg N / Mg dm]	n_{det} (n_{an})*	25%-quantile; median; 75%- quantile (minimum; maximum)** [kg N / Mg dm]
Organic N (N_{org})	147 (147)	11.4-17.6-27.2 (4.0; 38.4)	140 (140)	10.0-12.0-22.6 (4.2; 41.0)	124 (124)	9.3-11.4-22.8 (5.0; 35.5)	111 (111)	9.7-12.2-25.3 (4.7; 36.3)
Ammonium/ ammonia N ($\text{NH}_4^+/\text{NH}_3\text{-N}$)	146 (152)	1.6-3.4-6.4 (0.1; 13.0)	127 (139)	0.8-1.6-3.3 (0.1; 17.9)	120 (126)	0.5-1.3-3.4 (0.1; 17.0)	105 (108)	0.4-1.3-4.4 (0.1; 10.0)
Nitrate N ($\text{NO}_3^- \text{-N}$)	20 14*** (147)	0-0.1-0.9 0-0.5-0.9*** (0.0; 2.9) (0.0; 2.9)***	27 25*** (141)	0.0-0.1-0.6 0.0-0.1-0.6*** (0.0-4.9) (0.0-4.9)***	41 39*** (124)	0.0-0.2-0.4 0.0-0.1-0.4*** (0.0-1.9) (0.0-1.4)***	40*** (109)	0.1-0.4-0.5*** (0.0-2.1)***
Nitrite N ($\text{NO}_2^- \text{-N}$)	4 (136)	0.1-0.1-0.4 (0.0; 1.0)	14 (136)	0.0-0.2-1.0 (0.0; 1.8)	9 (120)	0.3-0.4-0.6 (0.2; 0.9)	8 (107)	0.0-0.3-0.6 (0.0; 1.0)

* n_{det} : number of detections; n_{an} : number of analysed samples ** values given only for the samples with detections

*** $\text{NO}_3^- \text{-N}$ was generated during composting and not artificially added

Tab. 2: Cumulative N emissions during composting.

Parameter	Number of experiments	Number of detections	N-emission up to the end of composting	
			25%-quantile; median; 75%-quantile (minimum; maximum)	
			[% $N_{\text{total-0}}$]	[kg N / Mg dm-0]
Ammonium N in the exhaust air ($\text{NH}_3\text{-N}$)	53	45*	5.4-23.2-46.5 (0.1; 89.8)	0.6-5.3-7.5 (0; 11.2)
Dinitrogen in the exhaust air (N_2)	42	24	0-1.9-10.5 (0; 39.5)	0-0.3-1.2 (0; 12.6)
Total N in the leachate	53	35	0-0.3-2.5 (0; 31.2)	0-0.1-0.3 (0; 10.3)

* Detections below 1 % $N_{\text{total-0}}$ and 0.2 kg N/Mg dm-0 were not considered

dm-0: dry matter of the initial substrate; $N_{\text{total-0}}$: total N-content of the initial substrate

Discussion

During composting, waste proteins (N_{org}) are ammonified into $\text{NH}_4^+/\text{NH}_3$. NH_3 may be stripped via exhaust gas while $\text{NH}_4^+/\text{NH}_3$ may become immobilised into humic substances or nitrified into NO_3^- via NO_2^- . NO_3^- and NO_2^- can further denitrify into N_2 . Water soluble organic N and inorganic N (NH_4^+ , NH_3 , NO_3^- , NO_2^-) can be leached. The occurrence and the intensity of transformations depend on the type of substrate used for composting and the milieu conditions during the process (Körner, 2008). The N_{org} content was relatively independent of the composting phase, but slightly higher values were detected in Composting Phase 1. $\text{NH}_4^+/\text{NH}_3\text{-N}$ was detected in almost all samples with peak values during Phase 1. $\text{NO}_3^- \text{-N}$ and $\text{NO}_2^- \text{-N}$ occurrences were seldom and their concentrations mostly low with an increasing number of detections in the later composting phases. In some experiments, NO_3^- was added at the beginning or during composting. The samples with additions were considered separately

in Tab. 1. Significant N-losses via leachate occurred only under very unfavourable composting conditions. In contrast, major N-losses into the exhaust air occurred in all experiments. Most significant were the releases of $\text{NH}_3\text{-N}$ during the thermophilic and the cooling phase (composting Phases 1 and 2; Körner, 2008). However, significant losses also occurred in the form of dinitrogen (N_2) in more than half of the experiments. They were most important during the cooling phase (Körner, 2008).

Conclusions

All compounds released during composting or after compost application may have harmful effects (see introduction) as long as the N compound is reactive and penetrates the environment. All N-compounds which are taken up by plants have positive effects since they act as a fertilizer. Inactive N-compounds are lost as fertilizer, but do not contribute to environmental pollution.

In composts, inorganic N-compounds and water soluble organic N-compounds can be considered as plant-available in the short term. They have a fertilizer value. Although N is commonly taken up in the form of NO_3^- and more seldom in the form of NH_4^+ by plants (Strasburger et al., 1983), the water soluble organic N-compounds as well as NO_2^- can be considered as available in the short term since it can be assumed that they are easily transformed in the soil into plant-available forms. Only a part of the short term available N will actually be taken up by the plants. N-losses (leaching, immobilisation in soil, releases into atmosphere) may occur during the application phase (mostly in the first year).

The major N-fraction of the compost is more or less immobilised into the humic compost matrix in a relatively stable manner and is therefore bound up in the medium to long-term. The ratio between medium and long term bound-up N is unknown. The long term bound-up fraction is lost as a fertilizer, but cannot contribute to environmental pollution since it is considered as inactive. In contrast, the medium term bonded fraction has an unknown fertilizer value, but may also be lost in the ways mentioned previously over many years.

N-compounds released during composting are today commonly lost as fertilizer. N_2 is inactive and therefore does not contribute to environmental pollution. In contrast, NH_3 and the water soluble compounds which were released via leachate can be considered as reactive.

Based on the results, the range of lost reactive/inactive N as well as of N-compounds with a fertilizer value can be estimated as described below. The estimation was based on the 25%-75% quantile values in Tab. 1 and Tab. 2 (the calculated values were rounded off at 5% intervals). The share of short term available organic N was estimated from the $\text{NH}_4^+/\text{NH}_3$ content (divided by 0.6) based on further investigations described in Körner (2008):

- Losses of reactive N during composting ($\text{NH}_3\text{-N}$; leached N): 5-50 % of the initial N
- Losses of inactive N during composting (N_2): 0-10 % of the initial N
- N-compounds with a high fertilizer value (short term available N): 10-35 % of the initial N (Phase 2); 5-40 % of the initial N (Phase 3-7)
- N-compounds with unknown behaviour regarding reactivity/inactivity and fertilizer value (medium and long term available N): 25-75 % of the initial N (Phase 2); 25-80 % of the initial N (Phase 3-7)

In conclusion, compost-N may affect the environment positively, but also negatively. Future tasks should focus on increasing the N-efficiency. For the fraction of released NH_3 in particular, it seems possible that technologies for N-recovery could be applied in composting facilities.

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Quality parameters of compost amended with chitin

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Key words: Chitin, Quality, Nitrogen, Compost, Microorganisms

Abstract

Trace amounts of chitin was added to two types of compost after the thermophilic phase and matured for additional two month. The chitin amendment altered the microbial diversity, increased the chitinase activity and increased the content of mineral N fivefold in compost based on municipal solid waste. The study indicate, that addition of chitin can improve the compost quality significantly.

Introduction

In Denmark, only 5 to 10% of the organic municipal solid waste (MSW) is biologically treated, i.e. composted and then recycled to farmland, the remainder is either incinerated or deposited. The main reason for this low recycling is that i) it is a challenge to organize a properly functioning collective sorting system; ii) dual collection of organic and inorganic waste is often assumed to be expensive.

Moreover, in the short-term, compost is generally a rather ineffective fertilizer, having only roughly 10-20% of the fertilizer effect of mineral N fertilizer (Magid et al., 2006), because the compost is stabilized and thereby has a very slow decomposition rate in soil (Pansu et al., 2003; Luxhøi et al., 2007). Thus, if the fertilizer value or at least its predictability could be improved, farmers may become willing to pay part of the expenses, and recycling could become an economically more viable solution for organic waste management.

The aim for this study was to investigate, to what extend addition of chitin (waste from scrimp production) to compost could increase the quality of the compost, with special emphasis on the content of mineral N.

Materials and methods

In an attempt to produce MSW-compost, and compost based on garden/park waste (GP) with special plant growth promoting properties, the University of Copenhagen, in collaboration with the compost company Solum A/S and the Danish Ministry of Food, Agriculture and Fisheries, launched the 'Functional Compost' research program. After the thermophilic composting phase, we applied trace amounts of chitin to the compost and let the compost mature for approximately two months.

Microbial diversity: The microbial diversity in the matured composts was examined by Denaturing Gradient Gel Electrophoresis (DGGE). Principal component analysis (PCA) was performed using the Unscrambler (Version 8.0, Camo).

Chitinase activity: Chitinase activity in extracts of the matured composts was detected as fluorescence from liberated 4-Methylumbelliferone (4MU) and was measured using a fluorometer with micro-titre plate reader at 377 nm excitation and 446 nm emission.

Nitrogen mineralization: The matured composts were amended to soil (20% vol.), and nitrogen mineralization was determined using standard methods in a 112 day long laboratory incubation experiment.

Results

The bacterial community of the MSW compost was clearly separated from the GP compost along the first principle component axis (Figure 1). For both types of compost, the part of the compost which had been amended with chitin was separated from the control compost, mostly by the second axis. MSW compost possessed significantly higher chitinase activity than the GP compost. For both compost types, the chitin amendment caused a significant increase in the chitinase activity (Tab. 1).

At maturity, the chitin amended MSW-compost had a five fold higher mineral N content compared to the unamended equivalent. Because the chitin was only added in trace amounts, the total N content of the chitin could at best only explain approximately 5% of the increased mineral N content of the

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compost. Thus, the chitin must obviously have induced a priming effect of almost 1800%, i.e. an additional mineralization of N that otherwise would be bound in organic form in the compost. This priming effect corresponded to 175 kg N ha⁻¹, when 20% vol. compost was applied to soil. During the soil incubation experiment, there was a significantly net N mineralization as a result of the chitin amendment. In fact the chitin amendment resulted in an additional N mineralization of 50 kg N ha⁻¹. Hence, the total priming effect of adding chitin to MSW compost was 225 kg N ha⁻¹. Chitin amendment to GP-compost, did not affect the mineral N content significantly.

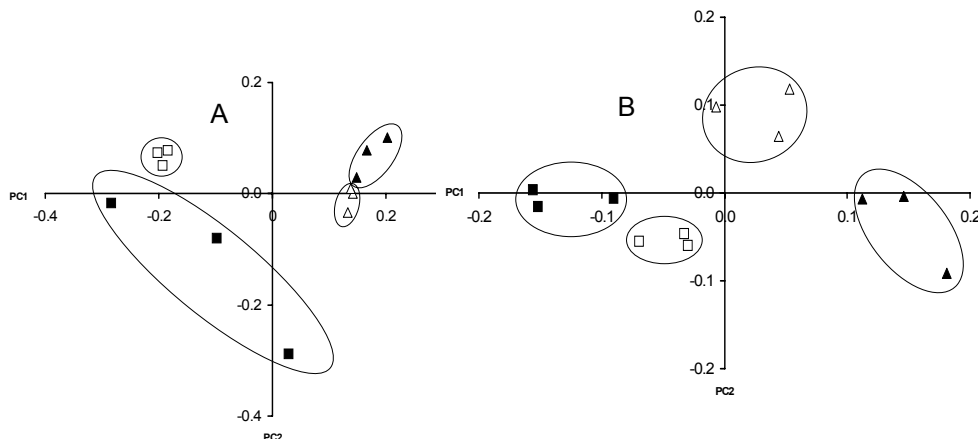


Figure 1: PCA ordination of bacterial (A) and fungal (B) diversity. GP-control (□), GP+ chitin (■), MSW-control (Δ), MSW+chitin (▲). The percentage of the total variation explained by each axis is PC1: 57%, PC2: 20% and PC1: 48%, PC2: 16% for plot A and B, respectively.

Tab. 1: Chitinase activity

	μmol 4 MU/hour x g dry weight	
	Without chitin	With chitin
Garden/park	0.46	0.76
MSW	3.97	5.83

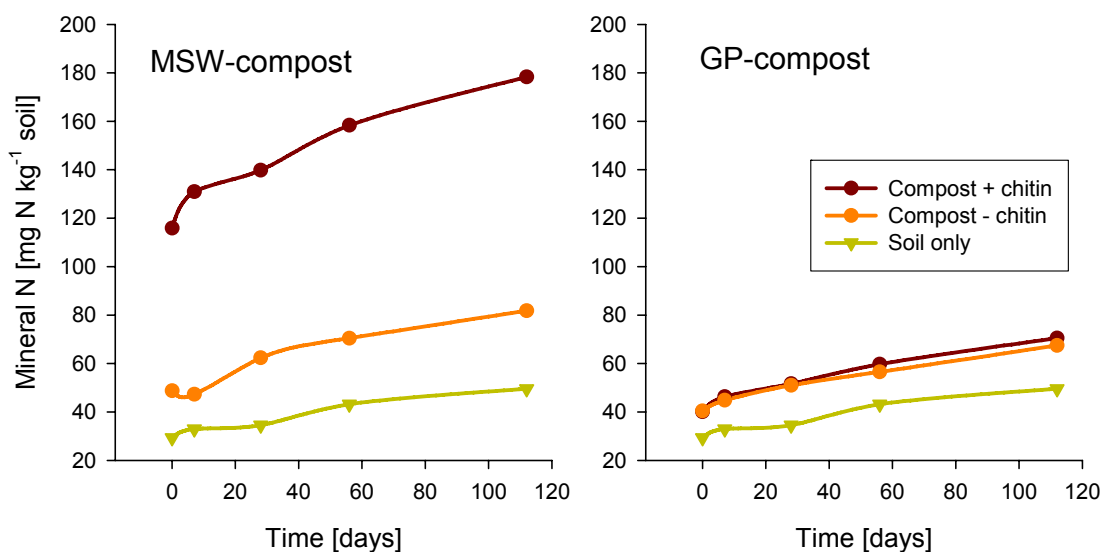


Figure 2: Soil mineral N during a 112 day long incubation experiment, as affected by incorporation of MSW- and GP-composts, with and without chitin amendment.

Discussion

A 20% vol. compost amendment may be appropriate for horticultural growth media, but for agriculture, a 2% vol. compost amendment is more realistic, which potentially would result in a priming effect of $22.5 \text{ kg N ha}^{-1}$, for the MSW compost. Results so far suggests, that addition of chitin to MSW compost cause a shift in the microbial diversity causing an increased chitinase activity, which promote an additional decomposition of the compost. The innovative aspect of these results is that chitin is the major polymer in shrimp waste. Hence, in principle, by adding shrimp waste to MSW compost, the compost quality can potentially be substantially increased.

Acknowledgments

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Quality characterization of separated animal manure bio-solids - key parameters important for composting and nutrient availability

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Key words: Animal manure, solid separation, nutrients, composting

Abstract

Separation of animal slurry into a liquid and a bio-solid fraction is a new opportunity for farmers in Denmark to comply with strict environmental regulation. A comprehensive investigation has been carried out in order to investigate the chemical variability among bio-solids from different separation plant types. A great variability among the samples in several parameters like, ash, nitrogen and phosphorous content was found. Knowledge about this variability can contribute to future recommendations about alternative utilisation methods of the bio-solids, such as composting.

Introduction

Denmark has one of the highest animal production densities in Europe. Technologies for separation of animal slurry constitutes a new opportunity for farmers to transport excess nutrients in the form of bio-solids over longer distances to areas without nutrient excess, in order to comply with strict environmental regulation. By separation, the slurry is divided into a liquid fraction containing soluble components such as mineral nitrogen and potassium and a solid, fiber rich fraction (10-15%), containing the majority of the organic matter. The two most common separation systems are based on either chemical separation (CHEM) which has a high efficiency with respect to phosphorous removal from the liquid fraction or mechanical separation (MEC) more efficient in removal of total solids. Additionally, a number of biogas plants, digesting animal slurry anaerobically, have installed a decanting centrifuge, separating the manure mechanically after the biogas procedure (DEC/BIO). Currently (2007), about 50 animal manure separation units are operating on farms and biogas plants in Denmark, separating about 3 % of all the animal slurry (27 million tons annually) (Birkmose, 2007). There are many initiatives to develop alternative utilization opportunities for the bio-solids, aiming at either land application or bio-energy production. Composting of the bio-solids could be one alternative, by producing either a stabilized product of reduced volume and weight facilitating export to areas/countries poor in organic matter, or a high quality product to be sold as an alternative for peat based soil improvers or growth media. However, the processing and utilization of bio-solids will be greatly influenced by their quality, i.e. content of nutrients and degradability. The objective of this study was to determine the variability in quality parameters of separated animal slurry bio-solids in order to make a foundation for suitable future recommendations of the best utilization methods for the individual types of manure bio-solids.

Materials and methods

Sampling of about 50 different types of bio-solids from various animal slurry separation plants in Denmark was carried out in the spring 2007. The samples originated mainly from pig farms and biogas plants treating mixed (pig and cattle) slurry, and a few from dairy and fur animal farms. Most of the samples were collected immediately after separation, whereas the rest had been stored (2-14 months) on farm before sampling. All samples were analyzed for total solids (TS) and ash content. pH, electric conductivity was measured in a 1:5 w.w. water suspension, total nitrogen was measured by Kjeldahl distillation and ammonia nitrogen was measured at spectrophotometry in a 1:20 w.w. 1 M KCL suspension. Total phosphorus was determined by digestion with concentrated nitric acid followed by measurement with molybdenum colour reaction by spectrophotometry.

Results

A significant variation among the samples was observed. An overview of the preliminary results is presented in table 1. The results presented are mean values from all samples within the grouping of three separation plant types which substantiates in some cases a relatively large variation within the groups, because within group samples represents both fresh and stored samples and in some cases samples from different animal types. The highest ash content, Ec, N- total and P total is observed for DEC/BIO samples. The highest total solids content is generally found in MEC samples but the lowest P concentrations are also found here. The total nitrogen concentration is generally highest in DEC/BIO samples, whereas the ammonia concentration is almost the same for the three bio-solid types.

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Table 1: Quality parameters of 44 samples of bio-solids from separated animal slurry. All parameters are presented as mean values with standard deviation in parentheses.

	TS %	Ash %	pH	Ec (uS/cm)	N total g/kg w.w.	NH ₄ -N g/kg w.w.	P total g/kg w.w.
DEC/BIO (n=10)	31.9 (6.5)	33.7 (8.9)	8.1 (1.2)	46.9 (24.3)	10.53 (2.28)	3.35 (1.83)	10.10 (5.64)
CHEM (n=22)	24.2 (5.3)	18.9 (6.6)	8.2 (0.5)	35.8 (13.7)	8.57 (2.56)	3.80 (1.37)	5.55 (1.76)
MEC (n=20)	34.3 (8.8)	8.8 (3.4)	7.8 (1.1)	25.8 (14.5)	6.64 (2.58)	3.22 (2.03)	2.55 (1.56)

Discussion

The great variability among the three different types of bio-solid was expected due to the different nature of the samples. In this experiment we only have information about the separation type and animal type. All information about feeding strategy of the animals, slurry treatment and storage that has a possible influence on the bio-solid quality (Møller 2002), is not included. Especially pre-treatment of slurry in anaerobic digestion plants (bio-gas) or just longer storage periods of the slurry, where it undergoes a decomposition process can lead to a decrease in total suspended solids, and contributes to a transfer of nutrients, especially nitrogen and phosphorus, between different fractions and chemical forms in manure (Henze, et al 1996). This can contribute to the explanation of the increased ash and nutrient content in DEC/BIO samples. The CHEM separation procedure is a relatively new technology applied on animal slurry, where the solids are precipitated with a chemical polymer followed by a mechanical separation. This treatment facilitates separation of the smaller particles from the slurry which contains the main part of the phosphorus (Masse, et al 2005) – explaining the increased phosphorus content in CHEM samples compared to MEC samples. The proportion of ammonium nitrogen relative to the total nitrogen varies from 32 % in DEC/BIO samples to 44 and 48 % in CHEM and MEC samples, respectively. If this relative high ratio of inorganic vs. organic nitrogen is maintained during a composting process the compost will be very attractive from a farmers perspective, since he can expect a relatively high nitrogen efficiency for his crops if the compost is incorporated rapidly into the soil upon application in the spring.

Conclusions

A great variability among the 44 samples from three different separated animal slurry bio-solids was observed on various parameters. Future recommendations on the use of the bio-solids can become very dependent on the type of separation. Some will be suitable for composting while others may be more suitable either for use in biogas plants or for direct incineration with energy recovery. An ongoing investigation of the phosphorus distribution, in the raw bio-solids and in composted bio-solids can further contribute to the understanding of phosphorous availability and the possible use of animal slurry bio-solids.

Acknowledgments

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Utilization of separated animal manure bio-solids – opportunities for improved nutrient cycling and reduced environmental impact, with Denmark as an example

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Key words: Animal manure, technologies, nutrient cycling, environment

Introduction

With the current development of industrialised animal production in certain countries or regions of Europe, for example Denmark, animal manure has become a major waste product, requiring safe, sustainable and sanitary management. If animal manures are utilised on arable land, fertilizer value and soil quality should be improved and negative effects on ecosystem and human health should be eliminated. Industrial technologies for treatment, separation or refinement of the animal manure are increasingly seen as solutions to these problems, just as they have been for urban sewage and waste.

The Danish manure scenario

Denmark has one of the highest livestock densities in Europe, and strict environmental regulation of agricultural production is gradually forcing farmers to implement new manure separation technologies. These concentrate most of the phosphorus and organic nitrogen in a solid fraction constituting only 10-15% of total volume (Moller et al. 2000), which can then be transported to land without nutrient surplus or utilized for other purposes, in order to avoid excess nutrient losses to the aquatic environment. Drivers for such measures will be further promoted by the upcoming implementation of the EU Water Framework Directive.

Therefore, a surge in the number of animal manure separation units has recently occurred in Denmark, and approximately 3 % of the all animal slurry (27 million tons annually) was separated in early 2007, producing around 65-95.000 tons (FW) of bio-solids (Birkmose, 2007). Although still a relatively small proportion, the emerging environmental industry predicts that up to 30-50% of all Danish manure may be separated within the next 5-8 years, producing up to 1.5 mio. tons of bio-solids.

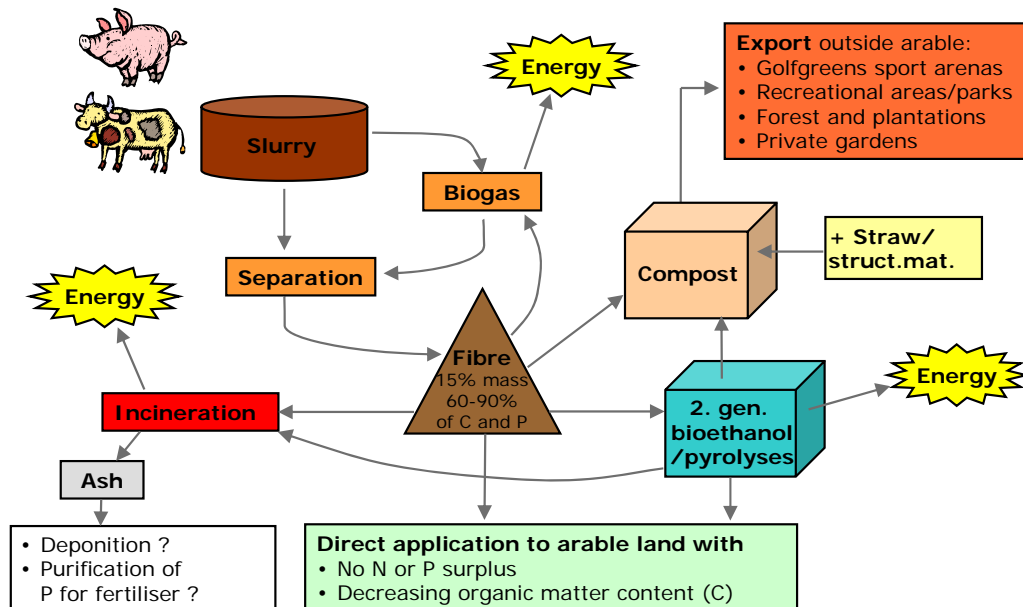


Figure 1: Utilisation opportunities for manure bio-solids

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Utilisation opportunities

The bio-solids fraction represents a valuable resource if utilized appropriately, both in terms of nutrients (N, P) and organic matter. The various opportunities for utilisation are depicted in Figure 1.

In Denmark, the consumption of peat based growth media and soil conditioners amounts to around 700.000 m³ of which about half is imported. More than half of this is utilized in the horticultural production industry, whereas the rest is sold for private gardening and floriculture. As peat is a very slowly renewable resource from natural areas of significant ecological value, many countries seek to diminish its exploitation, and if composted appropriately, the manure bio-solids fraction may be able to substitute a significant proportion of these peat based products (Jørgensen and Jensen, 2007).

However, the bio-solids fraction may also be used for bio-energy production, either in anaerobic digesters for methane or bio-ethanol production or directly in incinerators at combined heat and power (CHP) plants.

Phosphorous is a non-renewable mineral resource, which is an essential nutrient for current and future food and biomass production. Global P reserves are estimated to be depleted within +100 years at the current consumption and exploitation rates. Improved recycling and utilization of manure P is therefore crucial (Luxhøi et al. 2007), either in the form of raw or composted bio-solids or as incinerator ash after combustion of the bio-solids, which can then be exported to regions with soils depleted in P (e.g. the Baltic).

Some future scenarios for these utilization alternatives will be presented.

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Session 2.2:

Organic pollutants and heavy metals in organic waste products and feedstock materials

Input of organic pollutants to soil by compost and digestate application and their origin

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Key words: PAH, PCB, compost, fluxes, source apportionment

Abstract

Compost and digestate are important recycling fertilizers and have beneficial effects on soil parameters. However, they can contain significant amounts of organic pollutants. Here, input fluxes to agricultural soils by compost application are compared with other inputs for a wide range of organic pollutants (polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), dibenzo-p-dioxins and -furans (PCDD/F), polybrominated diphenyl ethers (PBDE), and perfluorinated alkyl substances (PFAS)). Total input of PCB, PAH and PCDD/F to Swiss agricultural soil was dominated by manure application and aerial deposition. However, if surface specific loads (i.e., loads per hectare based on a standard fertilization) are considered, source-separated compost and digestate were the most important inputs. Contrasting with the findings for PCDD/F, PCB, and PAH, it is suggested that total and surface-specific loads of PBDE to soil by compost application are low compared with other inputs. The total and surface specific loads for PFAS seemed to be lower for compost than for sewage sludge application. However, data for PFAS are very sparse. Evaluating characteristic ratios and molecular markers, the main source of PAH in compost was found to be pyrogenic, probably influenced mainly by liquid fossil fuel combustion. Multiple linear regression suggested some asphalt abrasion as an additional source.

Introduction

Composting (aerobic treatment) of crude organic kitchen waste and green waste represents an important and well-established part of waste management in Europe. Digestion (anaerobic treatment with or without subsequent aerobic treatment) has been promoted in recent years due to increasing efforts to combine recycling of organic materials with production of renewable energy. Some $31.5 \cdot 10^6$ t/y of municipal were composted in the 25 European Union member states (EU25, (European Communities, 2005)), which resulted in some $9.3 \cdot 10^6$ tonnes dry weight (t_{dw}) of compost. This amount is expected to increase, due the EC Council Directive on the Landfill of Waste (European Communities, 1999), which has implemented strict limits on the amount of biodegradable municipal waste that can be disposed of via landfill. Most compost and digestate, including the liquid fraction of the digestion process (presswater), is applied to agricultural land or is used in horticulture and landscaping as soil conditioner and fertilizer. This follows the sustainability principle and recycles nutrients. However, compost can contain significant amounts of pollutants (Amlinger et al., 2004, Brändli et al., 2005) that are introduced to the soil ecosystem by its application. The problem related to heavy metals has been recognized and statutory as well as voluntary quality standards have been put in place. It was shown that reduction of the heavy metal contents can only be achieved by thorough separation of the input materials at the source (Hogg et al., 2002), i.e., by excluding municipal solid waste, sewage sludge etc.

Little is known about the origin of organic pollutants and pesticides in source-separated compost (i.e., compost solely derived from crude organic kitchen waste and green waste; for review see (Buyuksonmez et al., 2000, Brändli et al., 2005)). Plausible input pathways of organic pollutants to

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compost and digestate are aerial deposition on green waste, accidental (i.e., improper separation of input materials, e.g., plastic debris) and/or deliberate input (e.g., pesticide application to fruits and vegetables). In order to reduce inputs, main sources of organic pollutants have to be identified, since these contaminants were not observed to be degraded efficiently during conventional windrow composting (Brändli et al., 2007b). We therefore selected molecular markers and corresponding ratios that are already part of conventional PAH analysis (or such that could be easily integrated) and applied them to our compost data to see whether source identification is possible.

To evaluate concentrations of pollutants in a specific matrix (in this case source-separated compost, digestate and presswater), it is important to compare inputs to the environment by different matrices. Such flux calculations are seldom carried out for compost and digestate. In this study, we therefore compared organic pollutant fluxes to soil by compost and digestate application with other inputs such as aerial deposition and sewage sludge application, providing a starting point for a better risk-benefit estimation of the application of compost and digestate to agricultural soil.

Materials and methods

Mean, minimum and maximum total loads to the Swiss agricultural area (comprising all arable soils, grassland, horticulture, orchards, and vineyards) and loads per hectare (ha, surface specific loads, based on a standard fertilisation) were calculated (for thorough description of the method see Brändli et al., 2007a). Whereas the total loads reflect the contribution for different contamination sources to agricultural soils on a national scale, the surface specific loads are relevant for plots where compost is effectively applied for fertilising. These comparisons were based on a standard fertilization of 70 kg P₂O₅. This corresponded to an application rate for farmyard manure of 2.9 t_{dw} (based on Reidy et al., 2003 and Walther et al., 2001), for sewage sludge of 1.1 t_{dw}/ha (P₂O₅ content of sewage sludge: 61 g/kg_{dw} (Külling et al., 2002)) for compost of 10.1 t_{dw}/ha (median P₂O₅ content in Brändli et al. (2007a): 6.9 g/kg_{dw}), for digestate of 9.7 t_{dw}/ha (median P₂O₅ content in Brändli et al. (2007a): 7.2 g/kg_{dw}), and for presswater of 4.9 t_{dw}/ha (median P₂O₅ content in Brändli et al. (2007a): 14.2 g/kg_{dw}, which is about 40m³, if assuming dry weight content of presswater of 13% and density of 1.05).

Additionally, the time to reach Swiss trigger or guide values for organic pollutants in soil as defined in the Ordinance Relating to the Impact on the Soil (OIS) (Swiss Confederation, 1998) solely by compost application and aerial deposition was estimated as outlined in Brändli et al. (2007a).

There are three types of characteristic PAH ratios, which can easily be integrated in conventional PAH analysis and may be used for source apportionment. They distinguish between: i) petrogenic and pyrogenic origin, ii) different fuels such as petroleum, coal and wood and iii) traffic and non-traffic sources of PAH. Additional molecular markers suggested for specific sources, i.e. retene (RET) for wood combustion, coronene (COR) for traffic sources and perylene (PER) for digenetic origin of PAH were included (Brändli et al., 2007a and references therein). Less established markers (4-H-cyclopenta[*def*]phenanthrene (cPHE) as pyrogenic marker and cyclopenta[*cd*]pyrene (cPYR) for woodburning and/or vehicle emission, (Brändli et al., 2007a)) were also assigned. If comparing emission ratios with ratios in recipient matrices (i.e. compost), it has to be considered that they could be altered compared to source data due to environmental fractionation and/or possible degradation. Degradation/evaporation during composting were considered as discussed in Brändli et al. (2007b) and environmental fractionation as suggested by Zhang et al. (2005). Additionally, a linear unmixing model taking into account the whole PAH profile was fitted to the data as described in Brändli et al. (2007a).

Results and Discussion

Mass fluxes of organic pollutants to soils

Total input of PCB to Swiss agricultural soil was dominated by manure application and aerial deposition (Figure 1a). However, if surface specific loads are considered, compost and digestate application were the most important inputs, outweighing aerial deposition by more than a factor of 25. PCB input by presswater was in the same range as input via sewage sludge. The time to reach the Swiss trigger value for plant production (0.2 mg/kg_{dw}, OIS (Swiss Confederation, 1998)) by compost or

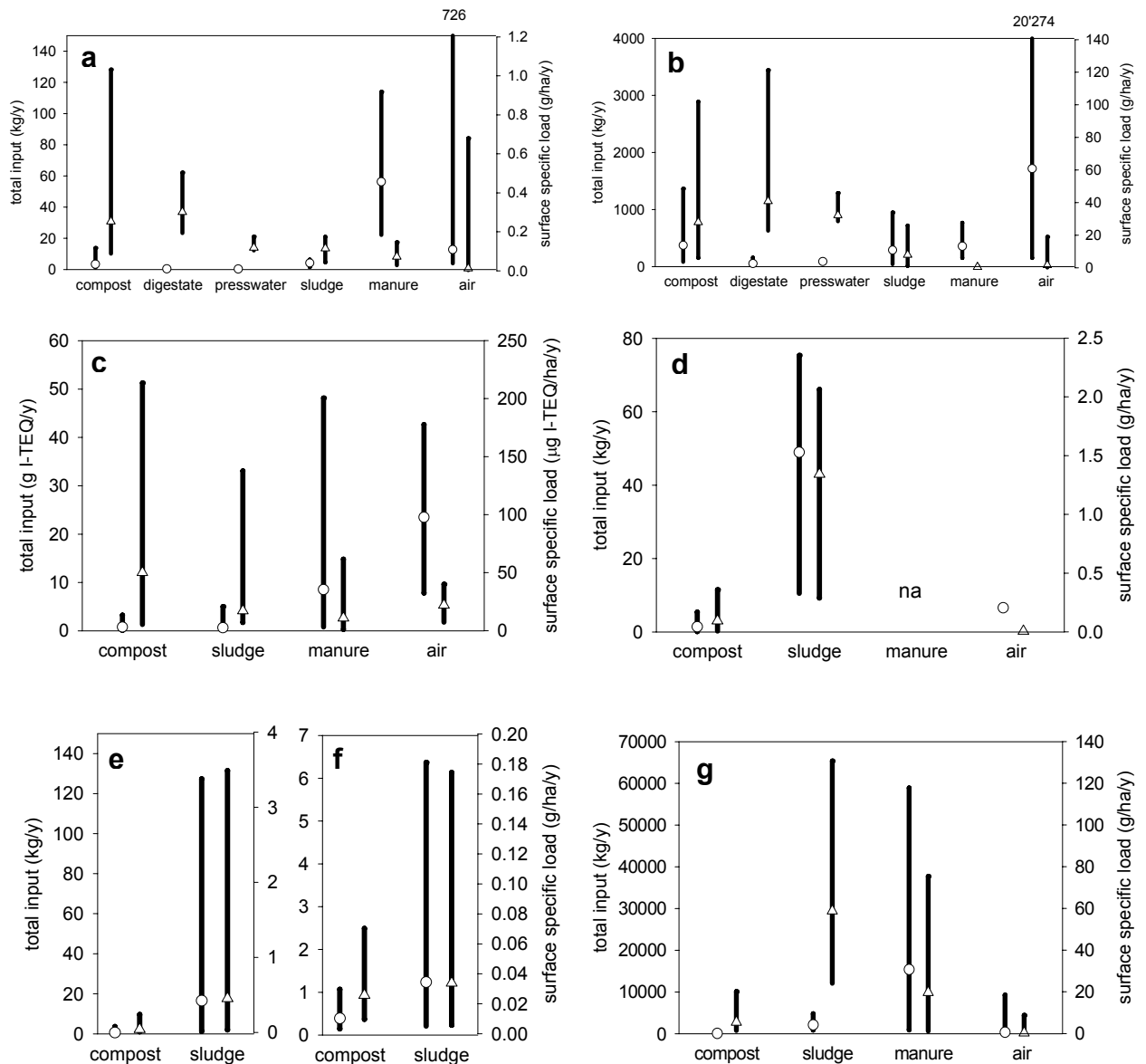


Figure 1: Average annual loads of organic pollutants from different sources: application of compost, digestate, presswater, sewage sludge (sludge), farmyard manure (manure) and atmospheric deposition (air) into agricultural soil: total loads to the Swiss agricultural area (○), surface specific loads (△), bars represent minimum and maximum values, na: not available. a) PCB (sum of PCB 28, 52, 101, 118, 138, 153, 180, Σ 7PCB), b) PAH (sum of 16 PAH defined by US EPA except DBA, Σ 15PAH), c) PCDD/F (toxic equivalents of the PCDDs and PCDFs), d) Σ 8BDE (sum of PBDE 28, 47, 99, 100, 153, 154, 183, 209), e) perfluorohexane sulfonate, f) perfluorooctanoate to perfluorododecanoate, g) di(2-ethylhexyl)phthalate. Adapted from Brändli et al. (2007a and 2007c)

digestate application (surface specific load scenario) and aerial deposition, which accounted for 4% of the total surface specific load, was estimated to 1400 years. This period was reduced by about a factor of ten if dioxin-like PCB were considered (Brändli et al., 2007c).

Total PAH loads introduced by compost, digestate and presswater application to Swiss agriculture accounted for 33% of the input from aerial deposition and exceeded loads by manure and sewage sludge application (Figure 1b). As for PCB, compost, digestate and presswater application were the most important input pathway if considering surface specific loads. They outweighed aerial deposition by more than a factor of 20 (Figure 1b). If the only inputs of PAH to soil were compost application (96% of the total surface specific load) and aerial deposition (4% of the surface specific load), it would take less than 50 years to reach the Swiss guide value for soil (1 mg/kg_{dw}, OIS, (Swiss Confederation, 1998)). At this level the law calls for actions to prevent further increase of the PAH.

Atmospheric deposition was the most important input pathway for PCDD/F to the total agricultural surface of Switzerland (24 g I-TEQ/y, Figure 1c). The total loads of sewage sludge and compost application were lower by almost two orders of magnitude. However, considering surface specific loads input by compost accounted for more than double the other inputs (Figure 1c). The time to reach the Swiss trigger value for soil (5 ng I-TEQ/kg_{dw} for PCDD/F (Swiss Confederation, 1998)) solely by compost application and aerial deposition (accounting for 0.04% of the total surface specific load) in absence of any removal process was estimated to be 112 years (with the starting level in soil 1.4 ng I-TEQ/kg_{dw}, references for deposition rate see Brändli et al., 2007c).

Even though data are limited, it is suggested that total and surface-specific loads of PBDE to soil by compost application are low compared with other inputs (Figure 1d). This contrasts with the findings for PCDD/F, PCB and PAH. A possible explanation is additional input sources of PBDE to sewage sludge (e.g., leaching from building materials via surface runoff), whereas for the other compounds aerial deposition plays the most important role. However, since PBDE are still released to the environment, increasing levels in most environmental compartments, including compost and soil, may be anticipated.

The total and surface specific loads for PFAS seemed to be lower for compost than for sewage sludge application (Figure 1 e-f). However, data is sparse or nonexistent (deposition data, concentrations in manure) and no final conclusion can be drawn. Total and surface specific loads of DEHP to soil by compost application were estimated to be below the input by sewage sludge or manure application (Figure 2g).

Characteristic PAH ratios and molecular markers

In general, characteristic PAH ratios and molecular markers in Swiss compost compared well with compost literature data (Brändli et al., 2005) and values from Swiss soils (Bucheli et al., 2004) even before taking into account possible alteration due to environmental processes and degradation during composting. However, not all ratios proved to be stable and they did not change consistently during composting and digestion (Brändli et al., 2007b). Among the constant ones, and hence possibly suitable for source apportionment in finished compost, were BaA/(BaA&BPE), FLT/(FLT&PYR), IPY/(IPY&BPE), 1,7-/(1,7-&2,6-)DmPHE and BaP/BPE. The remaining characteristic PAH ratios (ANT/(ANT&PHE), RET/(RET&CHR), (MFLT&PYR)/PYR, (MPHE&ANT)/PHE, ComPAH/Σ15PAH) changed inconsistently in three different composting studies (Brändli et al., 2007b) and are therefore not discussed here, but still listed in Table 1.

PAH ratios differentiating between petrogenic and pyrogenic sources (FLT/(FLT&PYR), BaA/(BaA&CHR), IPY/(IPY&BPE), 1,7-/(1,7-&2,6-)DmPHE pointed, before and after taking environmental fractionation into account (Zhang et al., 2005), towards a pyrogenic origin of PAH in compost (Table 1). There was no correlation between any of these ratios, before and after conversion, which could have been expected since they should all differentiate between the same sources.

It was not straightforward to distinguish between varying fuels as sources of PAH in compost. FLT/(FLT&PYR) ratios (median 0.6) were mostly in the grass/wood/coal combustion range, whereas for IPY/(IPY&BPE) about 46% of the samples had values below 0.5, indicating liquid fossil fuel combustion (Table 1). Conversion as suggested by Zhang et al. (2005), shifted FLT/(FLT&PYR) ratios more towards liquid fossil fuel combustion (about 0.13 units), which is reasonable for the PAH emission situation in Switzerland. However, IPY/(IPY&BPE) ratios were all above 0.5 after conversion, identifying grass/coal/wood combustion as the major PAH source. None of the 1,7-/(1,7-&2,6-)DmPHE ratios in compost and digestate was <0.45, which would identify vehicle emission but most, and after conversion, all BaP/BPE ratios indicated traffic sources of PAH. Values below 0.45 for 1,7-/(1,7-&2,6-)DmPHE ratios were expected at least for composts containing material from highways in the input material (special case: sample no. 31 and no. 47). High COR concentrations did not correspond with low 1,7-/(1,7-&2,6-)DmPHE ratios. Furthermore, COR as a marker for vehicle exhaust is debated

(Lima et al., 2003). In general, normalisation of molecular markers might be more informative than comparison of absolute values. However, ratios obtained by normalisation to the total sum (since no other parameters have been suggested, cPHE/ Σ 15PAH, cPYR/ Σ 15PAH, PER/ Σ 15PAH, COR/ Σ 15PAH) were not stable and they did not change consistently during composting (Brändli et al., 2007b), hampering source apportionment.

Overall, the application of PAH ratios and related molecular markers, originally derived from, and determined for characterization of specific emission sources, to recipient matrices such as compost or

Table 1: Characteristic PAH ratios, molecular markers, and respective values in compost and digestate (source Brändli et al. 2007a)

	petrogenic ^a	pyrogenic ^a	Swiss compost ^b	compost con ^c
ANT/(ANT&PHE)	<0.1	>0.1	0.10 (0.05;0.19)	<; 0.05 (0.03;0.10)
BaA/(BaA&CHR)	<0.2	>0.35	0.42 (0.27;0.50)	=; 0.55 (0.39;0.63)
FLT/(FLT&PYR)	<0.4	>0.4	0.60 (0.45;0.75)	=; 0.47 (0.31;0.64)
IPY/(IPY&BPE)	<0.2	>0.2	0.50 (0.44;0.61)	=; 0.58 (0.46;0.63)
ComPAH/ Σ 16PAH	0.3	0.7	0.87 (0.43;0.96) ^e	<; na ^d
(MPHE&ANT)/PHE	5	0.5	0.47 (0.22;3.07)	>/<; na ^d
(MFLT&PYR)/PYR	4	0.3	0.37 (0.23;0.75)	=/>; na ^d
1,7-/(1,7-&2,6-)DmPHE	0.45-0.7	<0.45 or 0.7-0.9	0.63 (0.50;0.76)	=; na ^d
	fuel combustion	grass/wood/coal combustion		
FLT/(FLT&PYR)	0.4-0.5	>0.5	0.6 (0.43;0.75)	=; 0.47 (0.31;0.64)
IPY/(IPY&BPE)	0.2-0.5	>0.5	0.5 (0.44;0.61)	=; 0.58 (0.46;0.63)
RET/(RET&CHR)	0.15-0.5	0.83 /0.96	0.19 (0.03;0.54)	>/=; na ^d
1,7-/(1,7-&2,6-)DmPHE	<0.45	0.7-0.9		=; na ^d
	diagenetic	pyrogenic		
PER/ Σ 16PAH	>0.05 ^k	<0.05 ^k	0.02 (0, 0.06)	>/<; na ^d
	non-traffic	traffic		
BaP/BPE	<0.6 ^d	>0.6 ^d	0.90 (0.53;1.4)	=; 1.50 (0.89;2.34)
1,7-/(1,7-&2,6-)DmPHE	>0.45 ^d	<0.45 ^d		=; na ^d
Markers				
COR/ Σ 15PAH	COR: vehicle exhaust		0.03 (0.003;0.12) ^e	</=; na ^e
CPHE/ Σ 15PAH	CPHE: pyrogenic marker		0.01 (0;0.02) ^e	>; na ^e
CPYR/ Σ 15PAH	CPYR: wood or traffic marker		0.003 (0;0.017) ^e	>; na ^e

a) prevalent discrimination levels, b) median (min, max) n=69 c) quantitative alteration during composting (Brändli et al., 2007b) < increase, = stable, > decrease during composting, respectively and ratios after applying conversion factor for air particles suggested by Zhang et al. (2005), d) conversion factor not available, e) dibenzo(a,h)anthracene was not determined, instead of Σ 16PAH it is referred to Σ 15PAH

ANT: anthracene, PHE: phenanthrene, BaA: benzo[a]anthracene; CHR: chrysene; FLU: fluoranthene, PYR: pyrene, IPY: indeno[1,2,3-cd]pyrene, BPE: benzo[ghi]perylene (BPE), ComPAH (Sum of FLT, PYR, BaA, CHR, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene (BaP), IPY, BPE), M: methylated, Dm: dimethylated, RET: retene, PER: perylene, COR: coronene COR, CPHE: 4-H cyclopenta[def]PHE, CPYR: cyclopenta[cd]PYR

soils (Brändli et al. 2006) for the purpose of source diagnosis of PAH seems to be of limited use. Correction factors such as those introduced recently by Zhang et al. (2005) as well as factors accounting for processes during composting (Brändli et al., 2007b) may be conceptually correct, but appear too simplistic for successful application to our compost data.

Source apportionment by linear unmixing analysis

Four characteristic PAH source profiles were identified in compost (Brändli et al., 2007a) if the entire PAH profile was considered (Figure 2). Source A corresponded well with a profile from asphalt (Tiefbauamt des Kanton Thurgau, 2006), before applying any conversion factors. This might be due to abrasion of roads surfaces by traffic that end up on plant material subsequently composted or of the composting plants pavement. However, asphalt is only one fraction of all particles/aerosols produced by traffic, such as tire rubbers, brakes, soot, etc., many of which also contain considerable amounts of PAH. Source B and D were similar to PAH profiles originating from green waste combustion (Jenkins et al., 1996) and traffic emission (Khalili et al., 1995) after accounting for processes during composting (Brändli et al., 2007b). Traffic emission indeed seems to be a plausible source, whereas green waste combustion might be of minor importance. Source C did not match any of the emission profiles from

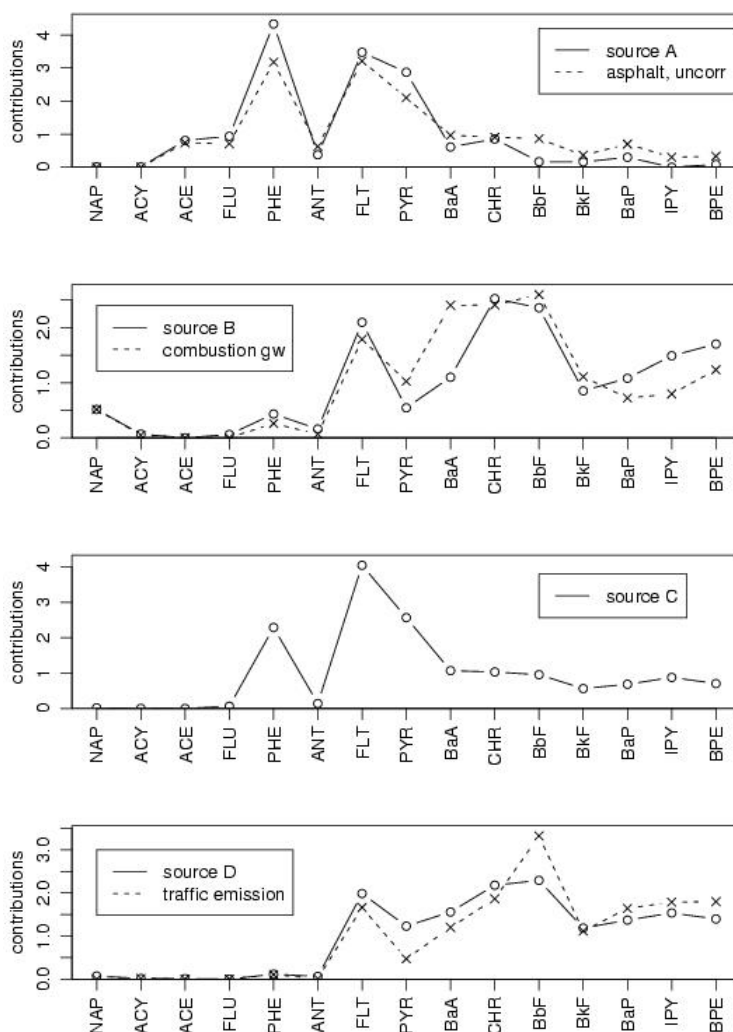


Figure 2: characteristic PAH source profiles in compost (n=55), including matching source's profiles. Combustion gw and traffic emissions are corrected for processes during composting (uncorr: uncorrected for environmental processes and alteration during composting, gw: green waste).

Source: Brändli et al., 2007a

the literature even if processes during composting (Brändli et al., 2007b) and between emission and deposition on input material (Zhang et al., 2005) were taken into account.

Conclusions

Overall, the data presented here provide a basis that allows for better balancing beneficial effects of compost application (e.g., soil improving and fertilizing effects, recycling of nutrients) against hazardous impacts. Even though PCB inputs to agricultural soils by compost application may outweigh inputs via aerial deposition and other recycling fertilizer application, loads were low and are even expected to decrease over the next decades due to the banning of PCB. Sources of PCB in compost and digestate are diffuse and aerial deposition is suggested to be the main input pathway. In contrast, PAH inputs to agricultural land by compost application can be considerable. Important sources may be emissions from traffic (asphalt and emissions from vehicles) as well as diffuse sources. Therefore, thorough studies to identify sources of PAH in compost are needed to lower PAH concentrations therein. The most realistic way of doing this seems to be a detailed investigation of input material at composting sites where PAH concentrations were high in repeated analyses, since indirect methods (characteristic PAH ratios, molecular markers, linear (unmixing) model) did not reveal clear results. Digestion and presswater need to be included in these evaluations since they were prone to even higher PAH concentrations. PCDD/F inputs to areas actually treated with compost may also be of concern. This seemingly high inputs of organic pollutants need to be counterbalanced with the apparent and well-documented beneficial aspects of compost application, such as soil improving properties and the sustainable management of natural resources. Further research is needed to appoint relevant sources of organic pollutants in compost, to identify possible stable degradation products and to assess to what extent they are biologically available.

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Heavy metals and organic contaminants in Bavarian composts – an overview

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Key words: heavy metals, organic contaminants, household biowaste compost, green waste compost, composted digestate from household biowaste

Abstract

In 2006, 30 compost samples taken from several plants (household biowaste, green waste, digestate from household biowaste composting plants) were analysed for pollutants: heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) and relevant organic contaminants (e. g. PAHs, PCDD/Fs, PCBs). Except for Cu, Zn, and PAHs, the contents determined mostly are low. Particularly with regard to the organic pollutants, green waste composts show lower concentration levels than household biowaste composts and composted digestates. Compared with former investigations, the pollution of composts seems slightly to decrease for most of the analysed parameters.

Introduction

The Bavarian Environment Agency investigates the content of ubiquitous contaminants in composts (household biowaste respectively green waste composts) since 1993 to get actual data on compost quality. These studies are focussing on (i) the concentration of heavy metals limited by the German Ordinance on Biowastes (BioAbfV), (ii) the content of several organic pollutants (PAHs, PCDD/Fs, PCBs). In 2000, the range of organic contaminants has been enlarged for other relevant substances.

Materials and methods

In the latest investigation 30 compost samples were tested (sampling: September 2006). They stemmed from (i) 12 household biowaste compost plants (HBW-CP), (ii) 12 green waste compost plants (GW-CP), (iii) 5 plants for anaerobic digestion of household biowaste (composted digestate, HBW-ADP), (iv) 1 plant composting paper sludge and green waste (PS_GW-CP). Besides the parameters mentioned above, following other organic contaminants were analysed: biphenyl, hexachlorobenzene (HCB), pentachlorophenol (PCP), o-phenylphenol, bisphenol A, di-(2-ethylhexyl)phthalate (DEHP), i-nonylphenol, tin-organic compounds, 1,3,4,6,7,8-hexahydro-4,6,6,7,8-hexamethylcyclopenta[g]-2-benzopyran (HHCB, Galaxolide[®]), 7-acetyl-1,1,3,4,4,6-hexamethyl-1,2,3,4-tetrahydronaphthalene (AHTN, Tonalide[®]), polybrominated diphenylethers (PBDE), thiabendazole, linear alkylsulfonates (LAS), perfluorinated surfactants (PFT), triclosan, methyl-triclosan.

The contents of heavy metals were determined by aqua regia dissolution/ICP-MS (Hg by solid phase-AAS); the organic compounds were analysed by organic solvent extraction/GC-(HR)MS (tin-organic compounds by GC-AED, LAS and PFT by LC-MS/MS).

Results

The study shows:

- Heavy metals: In the composts from HBW-CP, GW-CP, and HBW-ADP the concentration levels of each metal (Cd, Cr, Hg, Ni, Pb) are in the same order of magnitude (cf. Tab. 1); all samples meet the lower limits of BioAbfV. The concentrations of Cu and Zn in HBW composts are significantly elevated compared to GW composts. For the HBW composts, nearly half of the samples exceed the legal lower limit for Cu {70 mg/(kg dry wt.)}, 1 sample does not meet the lower limit for Zn {300 mg/(kg dry wt.)}. The lower limit for Cu is not fulfilled by 3 samples of HBW-ADP and the compost of PS_GW-CP.

Compared with former investigations no significant tendency in the heavy metal contamination is observed. A slight decrease is determined for Hg in composts of HBW-CP and GW-CP and for Cr and Ni in composts of GW-CP.

- Organic pollutants: They are not limited by the BioAbfV. Therefore, the study makes a contribution to get more information about organic contaminant loads. For PAHs, higher concentrations were found in composts of HBW-CP and HBW-ADP than in composts of GW-CP (cf. Tab. 1). Along the time PAHs

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show a significant reduction in *GW* composts respectively a constant load in *HBW* composts. PCDD/Fs in composts of *HBW-CP* and *HBW-ADP* are in the same order of magnitude compared to the composts of *GW-CP*. A similar result was obtained for PCBs (Σ 6 PCBs as well as dioxin-like WHO-PCBs). The contents of PCDD/Fs and PCBs decrease for the last years.

For most of the other organic pollutants, the concentrations in composts of *HBW-CP* and *HBW-ADP* are slightly higher than in composts of *GW-CP*.

Tab. 1: Concentrations of heavy metals and organic contaminants in Bavarian composts

Contaminant	<i>HBW</i> compost (N = 12) Median (min.; max.)	<i>GW</i> compost (N = 12) Median (min.; max.)	Composted digestate of <i>HBW-ADP</i> (N = 5) Median (min.; max.)
Cd [mg/(kg dry wt.)]	0.455 (0.259; 0.826)	0.383 (0.287; 0.529)	0.366 (0.146; 0.481)
Cr [mg/(kg dry wt.)]	22.1 (13.9; 44.7)	20.0 (13.5; 28.0)	23.0 (16.6; 35.8)
Cu [mg/(kg dry wt.)]	59.9 (43.4; 101.6)	38.9 (29.5; 64.0)	71.5 (24.7; 112.2)
Hg [mg/(kg dry wt.)]	0.126 (0.097; 0.195)	0.096 (0.073; 0.671)	0.097 (0.030; 0.122)
Ni [mg/(kg dry wt.)]	14.4 (9.6; 29.1)	12.0 (8.8; 23.0)	11.5 (9.5; 19.1)
Pb [mg/(kg dry wt.)]	37.4 (21.7; 51.4)	27.0 (17.0; 90.9)	26.8 (4.8; 33.9)
Zn [mg/(kg dry wt.)]	191 (141; 334)	147 (108; 249)	179 (88; 218)
PAH [mg/(kg dry wt.)]	2.31 (0.79; 7.73)	1.23 (0.40; 2.19)	2.68 (0.34; 3.89)
PCDD/F [ng I-TEQ/(kg dry wt.)]	6.47 (3.33; 32.4)	3.78 (1.22; 6.99)	6.00 (4.82; 10.6)
PCB (Σ 6 PCBs) [μ g/(kg dry wt.)]	22.2 (7.4; 38.3)	17.2 (4.8; 70.1)	25.6 (4.6; 66.5)
PCB (WHO) [ng WHO-TEQ/(kg dry wt.)]	2.37 (0.39; 4.46)	2.17 (0.61; 4.54)	2.82 (0.54; 5.65)
Biphenyl [μ g/(kg dry wt.)]	< 10 (< 10; 17)	< 10 (< 10; < 10)	< 10 (< 10; 11)
HCB [μ g/(kg dry wt.)]	1.9 (0.1; 7.2)	1.4 (0.7; 2.7)	1.9 (0.6; 5.2)
PCP [μ g/(kg dry wt.)]	15 (< 5; 37)	< 5 (< 5; 25)	15 (< 5; 29)
o-Phenylphenol [μ g/(kg dry wt.)]	< 10 (< 10; 21)	< 10 (< 10; < 10)	11 (< 10; 293)
Bisphenol A [μ g/(kg dry wt.)]	336.5 (< 10; 990)	10.5 (< 10; 43)	563 (23; 2860)
DEHP [mg/(kg dry wt.)]	1.15 (< 0.05; 2.69)	0.20 (< 0.05; 0.55)	1.76 (0.29; 4.75)
i-Nonylphenol [μ g/(kg dry wt.)]	153.5 (< 50; 331)	< 50 (< 50; 87)	324 (< 50; 421)
Monobutyl tin [μ g Sn/(kg dry wt.)]	4.3 (< 1; 8.6)	< 1 (< 1; 6.4)	6.8 (3.4; 19.7)
Monoctyl tin [μ g Sn/(kg dry wt.)]	< 1 (< 1; 5.8)	< 1 (< 1; < 1)	4.8 (< 1; 10.6)
HHCB [μ g/(kg dry wt.)]	13.7 (< 1; 46.3)	1.5 (< 1; 5.5)	62.2 (14.7; 69.8)
AHTN [μ g/(kg dry wt.)]	8.7 (3.6; 16.1)	2.1 (< 1; 7.7)	9.2 (6.1; 16.8)
PBDE [μ g/(kg dry wt.)]	23.4 (6.5; 89.2)	10.4 (1.2; 43.8)	26.3 (17.9; 41.4)

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Evaluating the Norwegian standard methods for the total and extractable heavy metal concentration in composts

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Key words: CAP-method, water-extraction, plant availability, total concentration, X-ray fluorescence

Abstract

The total concentration was determined after acid digestion and X-ray fluorescence, and the CAT-extractable and water extractable concentration (10kDa) of Zn, Cu, Cd, Ni, Cr and Pb in 17 composts were determined and compared with each other and in relation to the plant uptake in ryegrass. The acid digestion, XRF and CAT-extraction method of heavy metals correlated, whereas the 10kDa did not correlate. The 10kDa method was best in predicting the plant availability of heavy metals to ryegrass. In conclusion; total concentration of Zn, Cu, Ni, Cr and Pb can be determined by XRF and the CAT-method for predicting the plant availability of heavy metals can be replaced by water extraction for 24 hours and centrifugation at 60 000 g.

Introduction

By using compost in agriculture, an important quantity of nutrients and organic matter can be recycled. However, certain risks are involved in the use of composts, such as the presence of heavy metals. Compost application to agricultural land may result in enhanced heavy metal concentration in soil and plants but also in an increased plant growth. The heavy metal levels of urban solid composts depend on their source and composting process. Maximum admissible concentrations for heavy metals have been set for composts intended to be used as fertilisers in Norway (table 1). All organic fertilisers also have to be determined for its essential plant available nutrients according to the Norwegian standard 2890 (NS 2890). The main purpose of the study was to study the relationship between common methods used for determining the total and plant available (according to NS 2890) heavy metal concentration with the plant uptake and the second purpose was to investigate other methods that are better than them if they failed to predict the plant available fraction.

Materials and methods

Eleven household waste composts and 6 sewage sludge composts were collected from companies in Norway. All composts were air-dried, ground to a particle size of 1 mm and stored in plastic containers prior to analysis. A greenhouse experiment was conducted with ryegrass (*Lolium perenne*) grown in sand in plastic containers (12 cm diameter and 20 cm high) in three replicates. The ryegrass in each pot was cut twice before the sand beneath 5 cm depth was replaced. 5 g of dried and milled compost was added and plants were put back at the top. All plants were fertilised at growth day 1, 37 and 67 and harvested at 2 cm height at growth day 15, 30, 45, 60 and 75. Plants were oven dried (105 °C), and cut into small pieces prior to analysis. Concentration of Zn, Cu, Cd, Ni, Cr and Pb were analysed by inductively coupled plasma mass spectrometry (ICP-MS). The total concentration was determined after a microwave digestion at 240 °C of 0.3 g compost or plant sample in 3.5 ml ultrapure HNO₃ and 2 ml MQ-water. Plant available Cu and Zn was determined in 0.01 M CaCl₂ and DTPA according to the NS 2890 at the Bioforsk Laboratory (CAT-method). In addition to the two latter methods, the total metal concentration was also determined by a handheld X-ray fluorescence analyser at Holger Technology in Norway (except Cr) and plant available heavy metals was determined by shaking 4 g of compost in 40 ml of MQ-water for 24 hours, centrifuged at 60 000 g for 30 minutes (10kDa), diluted 1:10 (0.05 % HNO₃) and analysed by ICP-MS. Correlation and regression analysis were predicted using Minitab.

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Results

One compost fulfilled the criteria for class 1 and 5 composts for being used in organic farming, thus, their use in agriculture is not restricted by the heavy metal concentration (Hg was not considered).

Only 8 composts fulfilled the criteria for quality class 1, and it was mainly the concentration of Cd, Cu and Zn which resulted in a higher classification. Three composts were classified as quality 3 because of high Cd concentrations. The correlation between total heavy metal concentration determined after microwave digestion (Tot) and XRF are presented in table 1. The correlation between Tot and XRF were significant for all elements. The correlation between total and CAT extractable concentrations were significant for both Cu and Zn. The correlation between the plant available Zn and Cu determined with the CAT and after centrifugation (10KDa) were significant for Cu but not for Zn (Tab 1). The correlation between total concentration and 10KDa were only significant for Cu.

Tab. 1. Correlation between different methods used to determine the total and plant available heavy metal concentration in 17 composts

	Zn			Cu			Ni	
	Tot	XRF	CAT	Tot	XRF	CAT	Tot	XRF
XRF	0.927*			0.947*			0.675*	
CAT	0.735*	0.831*		0.797*	0.692*		nd	
10kDa	0.073	-0.228	-0.179	0.644*	0.579*	0.946*	-0.089	0.125
	Cr		Cd		Pb			
	Tot	XRF	Tot	XRF	Tot	XRF		
XRF	0.747*		nd		0.894*			
10kDa	-0.264	-0.322	0.978*	Nd	-0.016	0.023		

* significant ($P < 0.05$); nd: not determined

The R^2 for a linear regression model predicting the compost total heavy metal concentration and the 10kDa heavy metal concentration as a factor of the heavy metal plant uptake for all 5 harvest times are presented in table 2. R^2 for CAT-extractable Cu and Zn models were 57.0 and 18.4, respectively. The R^2 for the models were higher for the 10kDa than for the total concentration, except for Cd.

Tab. 2. The R^2 for a linear regression model predicting the total (Tot) and 10KDa fraction heavy metal concentration as a factor of the heavy metal plant uptake (plant) from 5 harvest times

	Zn		Cu		Ni		Cr		Cd		Pb	
	Tot	10kDa	Tot	10kDa	Tot	10kDa	Tot	10kDa	Tot	10kDa	Tot	10kDa
Plant	26.2	71.5	38.1	66.6	36.5	70.7	22.6	64.0	97.3	90.3	31.2	22.3

Discussion

The total heavy metal concentration can be measured by using XRF technology, which is a less time consuming method than the traditional digestion procedure. The total heavy metal concentration did not provide information about the plant availability, except for Cd. The CAT extraction correlated with the total compost concentration, and provides little new information about its availability because of the good correlation with the total concentration. The R^2 for the models for predicting the plant availability of Cu and Zn were higher for the 10kDa method than for the CAT method. The R^2 for the models predicting the plant availability were much higher for the 10kDa method than measurements of the total concentration in the compost, except for Cd and Pb. This clearly indicates that the heavy metal bioavailability is high when they are attached to small molecules or are water soluble.

Conclusions

Total concentration of Zn, Cu, Ni, Cr and Pb can be predicted by XRF-measurements and the CAT-method for determining the plant availability of heavy metals in composts can be replaced by water extraction (24 hours) and centrifugation at 60 000 g (30 min).

Determination of selected veterinary antibiotics and quaternary ammonium compounds in digestates of biogas plants in Austria

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Key words: biogas plant, quaternary ammonium compounds, antibiotics, digestate, LC-MS/MS

Introduction

Biogas typically refers to a (bio fuel) gas produced by the anaerobic digestion or fermentation of organic matter including manure, separate organic residues, biodegradable waste or any other biodegradable feedstock, under anaerobic conditions. Feedstock into the biogas power plants must be biodegradable in order to produce methane. Suitable feedstocks include (but are not limited to): biodegradable waste, slaughterhouse waste, catering waste, farm residues, separate collected organic waste, biomass like maize. Beside methane liquid digestate as a by-product is produced that is rich in nutrients and can be an excellent fertilizer dependent on the quality of the material being digested. If the digested materials include levels of toxic pollutants they might be present in the fertilizer. In many biogas plants in Austria farm waste such as manure is used as an ingredient for the fermentation process in combination with other feedstock such as food and farm waste.

Several studies revealed considerable amounts of veterinary antibiotics in manure samples (BLAC, 2003, Hamscher, 2002, Martinez et al., 2007c). Residues of antibiotics used for animal husbandry enter the environment either directly by spreading of manure. If used as feedstock in a biogas plant the digested residues are often applied as fertilizer.

Quaternary ammonium compounds (often known as QACs) are an economically important class of industrial chemicals. Because of their physical and chemical properties they are used as disinfectants, as surfactants, as anti-electrostatics (e.g. in shampoo), and as phase transfer catalysts. QACs belong to the group of cationic surfactants, hence, they are located at the phase boundary between the organic and water phase. They have therefore the capacity to attach themselves onto specific sites of the bacterial cell membrane and block the uptake of nutrients into the cell and prevent the excretion of waste products, which accumulate within its structure.

QACs are molecules with at least one hydrophobic hydrocarbon chain linked to a positively charged nitrogen atom, the other alkyl or aryl groups being mostly short-chain substituents such as methyl or benzyl groups respectively. The alkyl chain length determines the physical-chemical properties (water solubility, octanol/water partition coefficient, adsorption/partition coefficient on sediments, sludges and soils) (Boethling and Lynch, 1992), and may have also a decisive role in the fate of these contaminants in the environment.

Benzalkonium chloride (BAC) is a mixture of n-alkyl benzyldimethyl ammonium chloride homologues varying in n-alkyl chain length, where "n" represents an even number of carbons from C8 to C18. The most commonly encountered homologues are C12, C14 and C16 (Halvax et al., 1999), the biocidal properties of the individual homologues are known to be different (Gomez-Gomar et al., 1990). Other quaternary ammonium compounds are described as dialkyldimethylammonium chlorides (DDAC); they are mainly commercially used as a mixture with mainly C10 or C18 alkyl chain in many household products. The alkytrimethylammonium chlorides (ATAC) are also widely used in shampoo conditioning agents.

The aim of this study was to analyse several digestates for selected antibiotics and QACs to get concentration levels of these compounds and to estimate the impact for the environment.

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Materials and methods

Solvents and standards

Tetracycline (TC) (as its hydrochloride), trimethoprim (TMP), sulfathiazole (STZ), sulfadiazine (SDZ) and sulfamethoxazole (SMZ) were obtained from Sigma Aldrich (Vienna, Austria). Oxytetracycline (OTC) and chlortetracycline (CTC) (as its hydrochloride) were purchased from Fluka (Vienna, Austria). Sulfadoxine (SDO) and sulfadimidine (SDM) were delivered by Riedel-de-Haen (Seelze, Germany). Ciprofloxacin (CPFX) (as its hydrochloride) and enrofloxacin (ERFX) were both supplied by Bayer (Wuppertal and Leverkusen, Germany).

Dialkyldimethylammonium bromides with C10, C14 and C16 alkyl chain, benzyldodecyldimethylammonium chloride hydrate (C18) and dodecyltrimethylammonium bromide (C12) were supplied by Sigma Aldrich (Vienna, Austria); dialkyldimethylammonium bromides with C12 and C18 alkyl chain, benzalkonium chlorides with carbon chain C14 and C16, benzyldodecyldimethylammonium bromide (C12) and alkyltrimethylammonium bromides with carbon chain C14 and C16 were purchased by Fluka (Vienna, Austria). Marlon A375, a mixture of technical linear alkyl benzene sulfonate (LAS) used for ion-pair extraction was delivered by Contesio (Italy). All organic solvents used for sample preparation were residue analysis grade. HPLC grade solvents were employed for the HPLC work.

Cleaning and pre-treatment of laboratory glassware

To avoid the binding of TCs to silanol groups, before analysis of veterinary antibiotics, like some authors recommend (Hamscher et al., 2002), all glassware were washed with acetone, baked at 250 °C for at least 10 h, cooled, rinsed with a saturated methanolic solution of Na₂EDTA and, finally, air-dried. All glassware for the analysis of QACs was washed with CHCl₃ and baked at 250 °C for at least 10 hours.

Sampling

In a first step 12 digestates of biogas plants were sampled in 2006. All 12 samples were analysed for quaternary ammonium compounds whereas tetracyclines, sulfonamides and fluorquinolones were only measured in 6 samples. The analysed digestates derived from biogas plants which are mainly fed with catering waste, separate collected household waste, residues from food industry, maize, fat residues and manure.

Sample Analysis

Details of the applied analytical methodologies are described in earlier publications (Martinez et al, 2007b; Martinez et al, 2007c). For reason of quality assurance some samples (at least one in each series) have been additionally spiked by the investigated compounds. The recoveries were in the same range as for the analysis of manure and/or sewage sludge samples.

Results and discussion

Quaternary ammonium compounds

12 digestates samples were analyzed applying above mentioned methodology for QACs. Table 1 gives the results with a statistical evaluation of mean, minimum and maximum. Mean values were calculated only in cases where more than 50 % of the analyzed samples were above the LOQ. The LOD or zero were taken for values below LOQ or LOD, respectively.

Table 1: Statistical evaluation of the digestates from 12 biogas plants in Austria with mean, maximum and minimum values for the selected quaternary ammonium compounds

	Mean mg kg ⁻¹ dw	Max. mg kg ⁻¹ dw	Min. mg kg ⁻¹ dw
DDAC-C10	4,3	16	0,03
DDAC-C12		n.d.	n.d.
DDAC-C14		n.d.	n.d.
DDAC-C16		2,7	n.d.
DDAC-C18	0,7	6,2	< 0,025
BAC-C12	39	119	0,075
BAC-C14	16	49	0,051
BAC-C16	1,6	8,8	n.d.
BAC-C18	0,2	0,96	n.d.
ATAC-C12		0,44	n.d.
ATAC-C14		0,18	n.d.
ATAC-C16		0,67	n.d.
Σ QACs	62	180	0,35

The concentration levels in the analyzed samples ranged from below detection limit up to more than 100 mg kg⁻¹ dw. Especially, DDAC-C10 as well as BAC-C12 and BAC-C14 were found in higher concentration levels with mean concentration in the moderate mg kg⁻¹ range. All three compounds could be identified in all analysed samples. Maximum concentrations up to 119 mg kg⁻¹ were determined for BAC-C12 with a mean concentration level of 39 mg kg⁻¹. BAC-C14 and DDAC-C10 were detected in average concentrations of 16 mg kg⁻¹ and 4.3 mg kg⁻¹, respectively. BAC-C16, BAC-C18 and DDAC-C18 were also found in most of the samples, however, the concentrations were significantly lower than for the first three mentioned QACs. The alkyltrimethylammonium chlorides as well as DDAC-C16 were only occasionally found in the investigated samples whereas DDAC-C12 and DDAC-C14 could not be detected at all.

The potential inhibitory effect of selected QACs (DDAC-C8, DDAC-C10 and a mixture of BAC-C12, BAC-C14 and BAC-C16) was investigated at concentrations up to 100 mg L⁻¹ using a mixed, mesophilic (35°C) methanogenic culture (Tezel et al., 2006). A batch assay conducted at a range of QAC concentrations showed that QACs were inhibitory to methanogens at and above 25 mg L⁻¹. Tests with Vigilquat (a commercial mixture of four QACs, e.g. DDAC-C10 and three BACs) at a concentration of 50 mg L⁻¹ and above adversely affected anaerobic treatment of poultry processing wastewater which resulted in a significantly reduced methane production (Tezel et al., 2007). All investigations cited above have been conducted by quantification of the QACs performing a modified disulfine blue method (DIN 38409). This method however cannot distinguish between the QACs with different C-chain homologues. Uhl et al. (2005) investigated the effects of QACs for the respiration and nitrification inhibition under aerobic conditions. The first effects on the acute and chronic inhibition were determined for Benzalkonium chloride concentration about 1 mg L⁻¹ whereas the dialkyldimethylammonium chlorides were less sensitive (5 mg L⁻¹). Especially the compounds with a low homologue number were more effective than the C16 and C18 analytes. Similar results were observed by the EU Risk Assessment for DDAC-C18. Four tests on growth inhibition, respiration inhibition and nitrification inhibition with bacteria using DHTDMAC as test substance were investigated. Nitrifying bacteria were found to be the most sensitive microorganisms with the lowest EC₅₀ of 2.1 mg L⁻¹.

Considering the concentrations of the QACs in the digestate with a mean of 5 % dry weight maximum levels of 9 mg L⁻¹ (as a sum) and 6 mg L⁻¹ (BAC-C12) were detected. These determined concentrations could have effects on the nitrifying bacteria under aerobic conditions. Experiments under anaerobic conditions showed effect levels between 25 mg L⁻¹ and 50 mg L⁻¹ depending on the chain lengths. Moreover, it was shown that BAC-C12 (predominantly detected in the digestates) was more sensitive, and therefore an impact in the fermentation process and furthermore in biogas production cannot be completely ruled out.

Antibiotics

Six digestates samples were analyzed applying above mentioned methodology for tetracyclines, sulfonamides and fluorochinolones. The same procedure as for the QACs was used for the statistical evaluation of the results which are summarized in table 2. As it can be clearly seen, the digestates

were mainly contaminated with tetracyclines and to a lower extent with sulfadimidine. This is a clear sign that liquid manure was used for investigated biogas plants. Maximum concentration levels up to 1.3 and 1.4 mg kg⁻¹ dw were determined for chlortetracycline and oxytetracycline. These two compounds could be also detected in all analyzed samples resulting in mean concentration of 0.5 mg kg⁻¹ dw each. Tetracycline could be determined in 5 digestates whereas sulfadimidine could only be measured in two cases. All other investigated compounds were not found at all.

Table 2: Statistical evaluation of the digestates from 6 biogas plants in Austria with mean, maximum and minimum values for the selected antibiotics

	Mean mg kg ⁻¹ dw	Max. mg kg ⁻¹ dw	Min. mg kg ⁻¹ dw
Tetracycline	0,29	1,0	n.d.
Chlortetracycline	0,51	1,3	0,24
Oxytetracycline	0,53	1,4	0,13
Trimethoprim		n.d.	n.d.
Sulfadimidine		0,27	n.d.
Sulfadiazine		n.d.	n.d.
Sulfadoxine		n.d.	n.d.
Sulfathiazole		n.d.	n.d.
Sulfamethoxazole		n.d.	n.d.
Ciprofloxacin		n.d.	n.d.
Enrofloxacin		n.d.	n.d.

In experiments using laboratory scale digestors at 37 °C, OTC levels in the manure slurry decreased from about 10 mg L⁻¹ to 4 mg L⁻¹ in 64 days, yielding a calculated half-life value for OTC destruction of 56 days (Arikan et al, 2006). The presence of OTC in manure inhibited biogas production by 27% but did not affect biogas methane content or the overall removal of volatile solids. In contrast an Italian group (Lallai et al, 2002) investigated OTC which started to reduce methane production at concentrations above 125 mg L⁻¹. Sanz et al (1996) showed that chlortetracycline with an IC₅₀ (Inhibit Concentration) of 40 mg L⁻¹ are very powerful inhibitors of anaerobic digestion.

Considering a dry weight of the digestates of approximately 5 %, the digestates would be contaminated with 70 µg L⁻¹ OTC and 65 µg L⁻¹ CTC. The concentration levels of selected antibiotics in the digestate were well below the effect concentrations shown above and no effects on the biogas production are expected for these investigated digestates.

Conclusions

Depending on the biogas plant and the products which were used for the fermentation process, maximum concentration of a single QAC compound (i.e. BAC-C12) of 119 mg kg⁻¹ dw was reached, whereas the sum of the selected QACs varied between 0.35 and 180 mg kg⁻¹ dw. The determined concentration levels were higher than those detected in sewage sludges. Depending on the dry weight content of the digestate these concentrations might even effect biogas (i.e. methane) production, decrease the energy outcome and might lead to a possible economic loss. It is assumed that degradation of the investigated QACs did not occur or was very low.

In all six analyzed digestates samples antibiotics from the group of the tetracyclines were detected whereas no fluorquinolones could be found. These results confirm that part of the input material were liquid manure from pig and cattle, where tetracyclines are often prescribed. The fluorquinolones are often prescribed in poultry farms which have not been present in this study. The determined concentration levels were below 100 µg L⁻¹ where effects on the biogas production can be ruled out. However, highly contaminated manure with a concentration of approximately 100 mg kg⁻¹ dw (5 mg L⁻¹) which has been reported in previous studies (BLAC, 2003, Hamscher, 2002) might effect the methane production.

Acknowledgments

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Determination of Organic Contaminants in Compost and Digestates in Baden-Württemberg, South-West Germany

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Key words: Compost, Digestates, Soil, Organic Contaminants, GC-MS.

Abstract

A monitoring study was performed to get information about the presence of various persistent organic pollutants in samples of garden composts, in the output material of 16 composting plants and in soil samples in the state of Baden-Wuerttemberg, South-West Germany. Among the different compounds and compound classes that were investigated were polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), polybrominated flame retardants (PBDEs) and estrogen active nonylphenols. All compounds and compound classes selected were found in the samples in the µg to mg/kg dry weight (d.w.) range. The highest concentrations were found for the PAHs, which were between 1,2 to 3,5 mg/kg d.w. The concentrations of selected PCBs were between 20 and 35 µg/kg d.w. For both classes of substances as a tendency lower concentrations were found in green compost than in other types of samples. Seasonal variations in concentration were observed for PAHs, nonylphenols and DDE, which is a degradation product of the insecticide DDT. For PCBs and PAHs the concentrations found were generally lower than the concentrations allowed for agriculturally used sewage sludge in Germany (Sewage Sludge Ordinance AbfKlärV 1992) and defined in regulations in some European countries, e.g. Denmark, for organic pollutants in compost.

Introduction

Compost and digestates are so-called 'waste fertilizers' which are widely used as soil amendment and as a medium to grow plants, since they contain nutrients (N, P and K, usually in the low percentage range referring to dry weight). Like sewage sludge, however, they can also be contaminated by heavy metals (e.g. Pb, Cd, Cr, Ni, Hg, Cu, Zn) and organic pollutants (e.g. polychlorinated dibenzodioxins PCDDs, biphenyls PCBs, polycyclic aromatic hydrocarbons PAHs and many others) in varying concentrations. Regarding agricultural use German legislation (Düngemittelverordnung DüMV; Bioabfallverordnung BioAbfV) defines limits for the concentrations of heavy metals in composts, but limits for the concentration of organic parameters are missing; for sewage sludge concentration limits exist for PCDDs, PCBs and PAHs (Klärschlammverordnung AbfKlärV, based on EU directive 86/278/EWG). The usage of composts and digestates in agriculture and gardening should not (substantially) increase the concentration of these pollutants in the soil.

Materials and methods

Compost samples were taken in autumn 2005 (»summer samples«) and spring 2006 (»winter samples«) from biowaste composting plants (10 in total), green waste composting plants (3 in total) and digesting plants (3 in total) having a capacity of 2.500 to 84.000 metric tons *per annum*. The following substances or substance classes were selected as analytes in this study: polycyclic aromatic hydrocarbons (16 US-EPA PAHs including benzo(a)pyrene), polychlorinated biphenyls (the six »indicator« PCBs), polybrominated flame retardants (polybrominated diphenyl ethers (6 PBDEs with 2-7 Br) and tetrabromobisphenol A (TBBP A)), phenolic substances (e.g. the antioxidants butylhydroxytoluene BHT; nonyl- and octylphenol), chlorinated substances (chlorobenzenes with 3-6 Cl; and the disinfectant triclosan), di-(2-ethylhexylphthalate (plasticizer), synthetic musk fragrances (galaxolide HHCB, tonalide AHTN), the insecticide DDT and the metabolite DDE (dichlorodiphenyldichloroethylene). See Fig. 1 for the structural formulae of the selected analytes.

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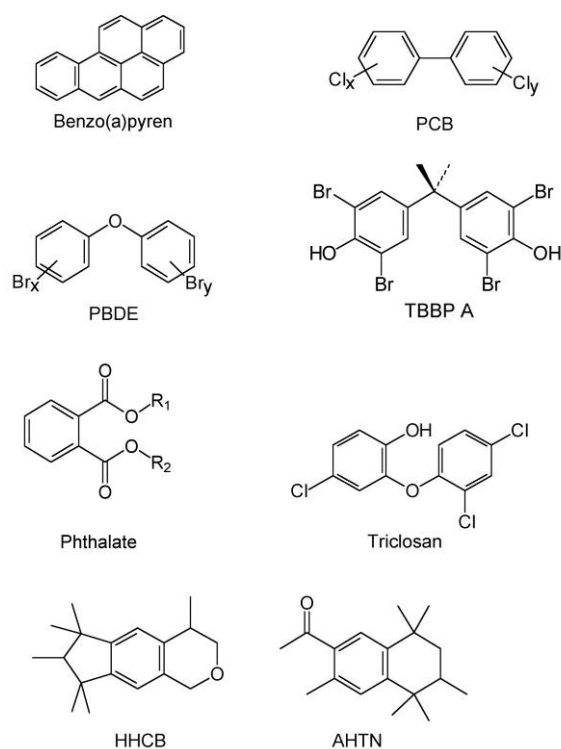


Figure 1: Structural formulae of some organic substances and substance classes investigated in composts and digestates

The samples were freeze-dried, grinded and Soxhlet extracted. Four aliquots of each of the Soxhlet-extracts were taken (aliquot 1 to 4) for the analysis of four groups of analytes with similar properties and investigated separately by GC-MS. Quantitation was performed using the isotope dilution method (Fig. 1).

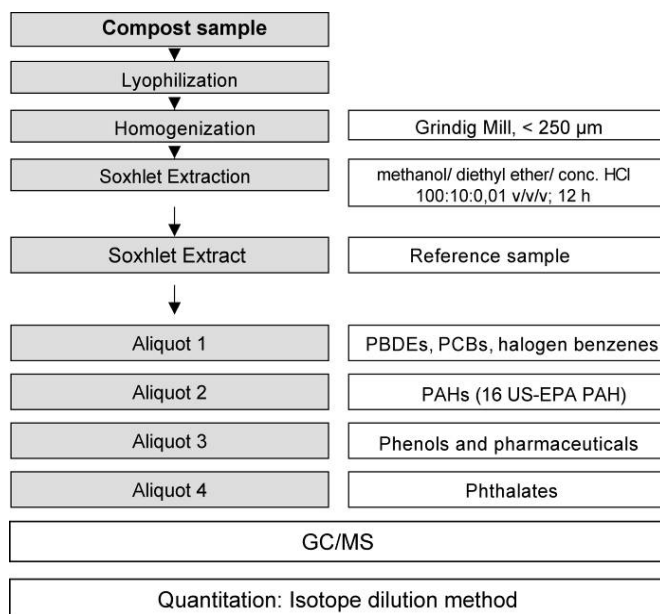


Figure 2: Analytical method used for compost analysis

Results and Discussion

The concentrations of the investigated pollutants in the different samples were in the range of less than one $\mu\text{g}/\text{kg}$ dry weight up to the low mg/kg range. The box plot of concentrations found shows that PAHs, DEHP and nonylphenols are the dominating substances/ substance classes in all samples.

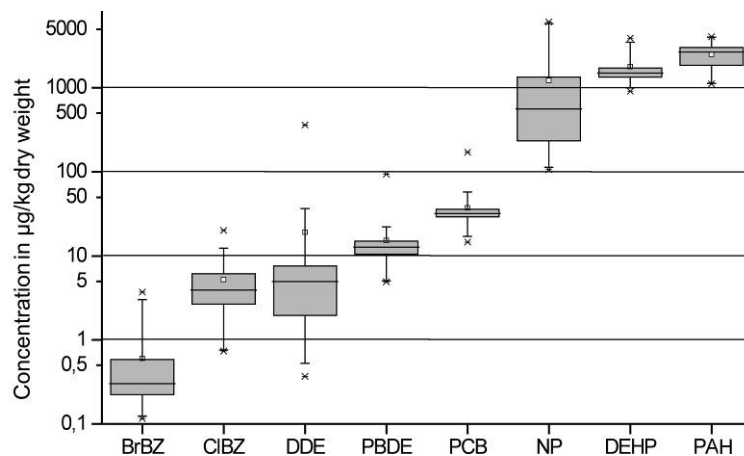


Figure 3: Box Plot of concentrations of organic pollutants found in biowaste composts, green waste composts and digestates (N = 29 samples; BrBZ, bromobenzene; ClBZ, chlorobenzene; DDE; dichlorodiphenyldichloroethylene; PBDE, polybromodiphenyl ethers; PCB; polychlorobiphenyls; NP, nonylphenol; DEHP, diethylhexylphthalate; PAH, polycyclic aromatic hydrocarbons;

As a tendency green waste compost samples were less contaminated than biowaste composts or digestates (see Fig. 3 for nonylphenols). The concentrations of PCBs, PBDEs and chlorobenzenes were comparable in biowaste composts and digestates. The concentrations of PAHs, nonyl- and octylphenols, DEHP and DDE in the digestates were higher than in biowaste composts. An explanation for this finding may be a different degree of contamination of the input material, differing input materials at all or different degradation conditions in the three kinds of samples.

Differences between »summer« and »winter samples« could be shown for PAHs, nonyl-/octylphenols and the DDT metabolite DDE in the case of green waste (Fig. 4 and 5). An explanation for this finding might be that heating in winter is connected with a higher consumption of fossil heating oil, which leads to an increase of PAHs (atmospheric source) in the colder season. There is a higher contamination of the input material of green wastes during the vegetation period in summer by octyl- and nonylphenols and also DDE. Despite of being banned, DDT is obviously still being used giving rise to relatively high concentrations of the metabolite DDE.

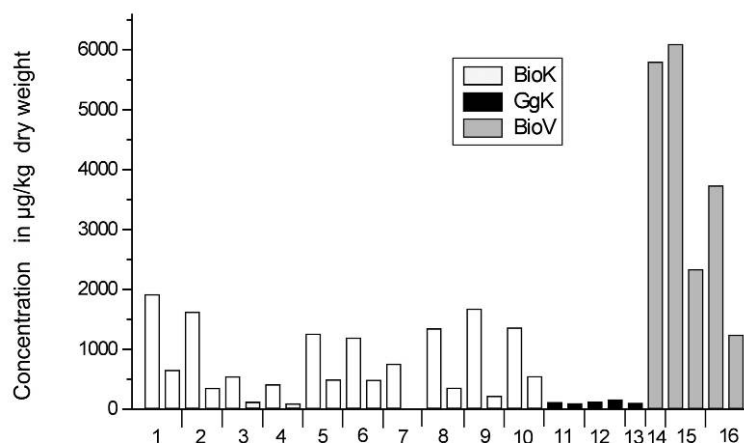


Figure 3: Concentrations of nonylphenol in biowaste and green waste composts and in digestates (BioK, biowaste compost; GgK, green waste compost; BioV, biowaste digestate).

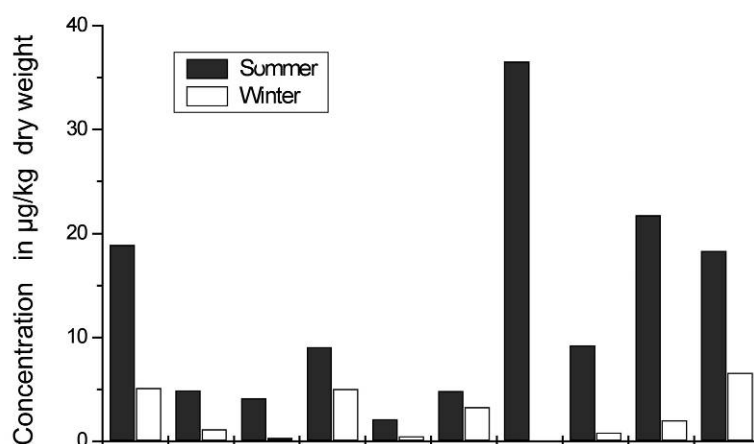


Figure 4: DDE in 10 summer and winter samples of green waste

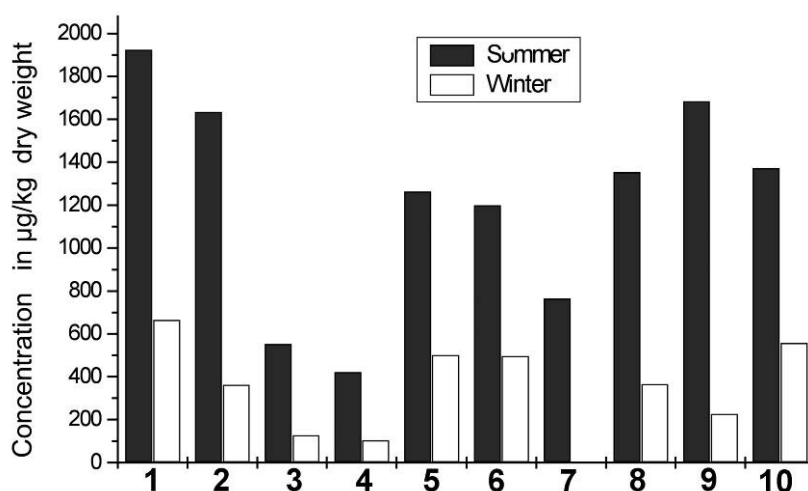


Figure 5: Nonylphenols in 10 summer and winter samples of green waste

Conclusions

The concentrations found for the selected analytes are in agreement with values reported in literature (Tab. 1). PAHs, phthalates and alkylphenols are the dominating substance classes in composts being present in up to mg/kg concentrations.

One should be aware that especially benzo(a)pyrene is a highly toxic, carcinogenic compound. The soil concentrations of organic pollutants differ strongly; however, based on our preliminary investigations of soil samples it can be expected that in some cases the soil concentrations are a factor of 3 to 10 lower than that of composts. In some countries (e.g. Denmark, Switzerland) there are concentration limits for PAHs in composts ranging from 3 to 10 mg/kg dry weight, which are much higher than the concentrations found in our study. As a basis for the evaluation of potential risks of compost usage data of both the concentrations of such pollutants in compost and in the soil ('background') have to be known. Our study shows, that in many cases the concentrations in composts are at least in the same order of magnitude than in soil, but they can also be much lower. Compared to sewage sludge allowed for agricultural usage the concentrations in compost are also much lower.

Tab. 1: Comparison of persistent organic pollutants in biowaste composts, sewage sludge and soil (concentrations in µg/kg d.w.)*

Substance	Biowaste composts [µg/kg d.w.]		Soil	Sewage sludge	Regulation for compost (country)
	Present study	Ref.*			
PAH (16 US-EPA PAK)	2.659	2.448	Ref.** 190-820	Ref.*** >3.000	3.000 (DK) 6.000 (AT) 4.000 (CH) 10.000 (LUX)
DEHP	1.400	300-18.000	300-700	n.n.-58.000	50.000 (DK)
Nonylphenols	560	n.d.-2.500	40	90-53.000	30.000 (DK)
PCB (6 indicator PCB)	33	40	<10	n.n.-765.000	100 (LUX) 200 (AT)
PBDE	13	10	<10	20-460	
DDE	5.0	8.1	0.6-7.8	n.n.-564.000	

*) Brändli, R., Kupper, T., Bucheli, T., Mayer, J., Stadelmann, F.X., Tarradellas, J. (2004): Vorkommen und Bedeutung von organischen Schadstoffen in Kompost, Gärgut und organischen Abfällen - Literature study; **) Amlinger, F., Pollak, M., Favoino, E. (2004): Heavy metals and organic compounds from wastes used as organic fertilisers, Final report. ***) own measurements

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Positive and negative impacts of composting and/or anaerobic digestion of sewage sludge on soil, plant and water

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Key words: toxicity, organic pollutants, accumulation, mineralization, microbial diversity

Abstract

This paper deals with the safety and agronomic efficiency of an organic waste (sewage sludge) with respect to their treatment (anaerobic digestion and compost) and chemical contamination (PAH). Experiments, carried out at various scales (microcosms, lysimeters, field), allow to evaluate the fate of organic pollutants in soil (mineralization, bound residues formation), the transfer of pollutants to plant and water and the positive or negative impact of the waste on plants (growth, root nodulation, genotoxicity) and soil biological properties (diversity and activity). The results underline that the fate of organic contaminants is dependent on the type and quantity of organic matter present in the soil as well as in the waste, highlighting the role of the treatments. Depending on the type of sludge, negative and positive impacts were measured : as a general case, the raw waste induced the more pronounced effects whereas the transformed one was without impact for the targeted assays.

Introduction

Spreading of solid waste like sewage sludge in agricultural land enables the recycling of nutrients for plant growth. However, there is a growing concern for organic pollutants present in this waste and their possible transfer to the soil-plant system and, by leaching, to the aquifers. Hence, it is important to assess the safety and agronomic efficiency of this waste with respect to their treatment and their chemical content. In the framework of the EU project BIOWASTE (QLK5-CT-2002-01138), studies were conducted to investigate how composting and anaerobic digestion could affect the availability of organic pollutants to plants, to evaluate the risk of organic pollutant leaching and the potential positive or negative impacts of the sludge on plants and soil biological properties. This latter was realised through the development of bioassays for the characterisation of the agronomic and environmental impacts of organic fertilisers adapted to agronomic matrices.

Materials and methods

For this purpose, an urban liquid raw sludge (LRS) was anaerobically digested (DS) and then composted (CS) on a real wastewater treatment plant.

The LRS, DS and CS were tested through laboratory bioassays to estimate their impacts (i) on plants growth (barley, wheat and carrot), (ii) on the accumulation of organic pollutants on roots or on root-adhering soil, (iii) on the symbiosis of *Rhizobium* and white clovers, (iv) on the genotoxicity to *Vicia faba* measured through micronuclei formation and (v) on the microbial diversity (PLFA and TTGE) and activity (deshydrogenase).

Microcosms were set up with 1.8 kg of a loamy clayey soil amended with the LRS, DS and CS spiked with ¹⁴C-labelled benzo[a]pyrene to study mineralization, formation of non extractable residues and transfer to water and wheat (Mougin et al., 2006).

Outdoor studies were also conducted in lysimeters containing 150kg of three different soils including the one used in microcosms. The impacts of LRS, DS and CS were measured on carrot and barley production, organic pollutant accumulation by plants, amounts of organic pollutants transfer to leachates and microbial diversity assessed by TTGE (Kuntz et al., 2008).

Lastly, a long term field experiment (30 years) provided data on the fate of organic pollutants in a sandy soil after repeated applications every 2 years for 20 years (1974 to 1991) of 100t/ha of sludge containing low amount of benzo[a]pyrene (Patureau et al., 2007).

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Results

Agronomic and environmental impacts of organic pollutants after sewage sludge application

As a general outcome, the raw sludge (LRS) induced the more pronounced effects whereas the composted (CS) one was without impact in our bioassays. As shown on figure 1, crop yields were increased depending on the type of sludge, as were also increased PLFA and dehydrogenase activity measurements performed on the microbial compartment of the soil during microcosms incubation.

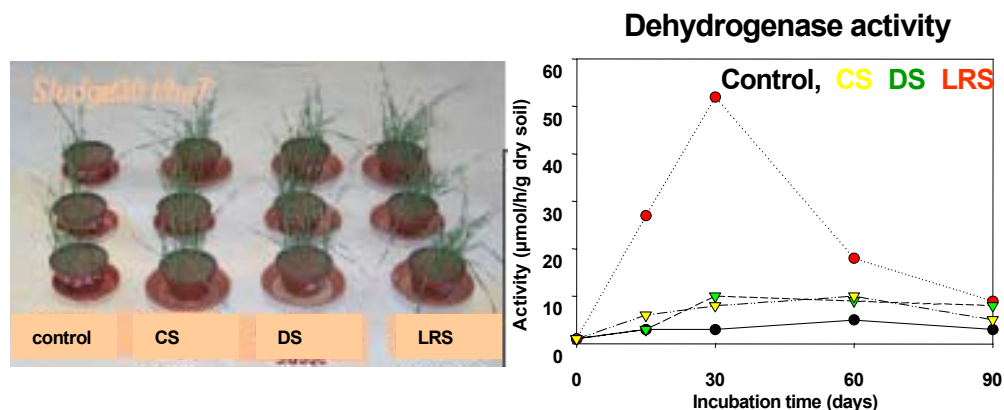


Figure 1: Effect of sludge application on biomass production (a) and on soil microbial community (b) with respect of their treatment.

Nevertheless, some negative impacts were also noticed in the soils supplemented with the sludge, particularly with LRS and DS. As shown in the table 1, the root nodulation in the *Rhizobium/Trifolium* symbiosis was decreased, and genotoxic effects were detected in the root cells of *Vicia faba*.

Tab. 1: Impact of sludge application on symbiosis and on genotoxicity

Sludge	Inhibition of nodulation (% of soil alone)	Number of micronuclei (by root cell)
CS	30	0 - 1
DS	50	1 - 5
LRS	84	1 - 4

Dynamic of organic pollutants after sludge application

The sludge samples were shown to be contaminated by organic chemicals, namely polycyclic aromatic hydrocarbons (PAH). High amount of pyrene were measured in the DS and CS, not in the LRS. In lysimeters, organic pollutants were only measured in the sandy soil (2.2% of organic matter) amended with CS. The transfer of organic pollutants to plants (carrots) was observed only for CS (0,8mg pyrene /kg dry material) and DS (0,6mg pyrene /kg dry material) in the diluted sandy soil (0,7% of organic matter). The transfer of organic pollutants to leachates were negligible. In microcosms, ¹⁴C-labelled benzo[a]pyrene was weakly mineralized (closed to 0% for LRS and around 1% for DS and CS) and poorly stabilized in non extractable residues (25 to 35%), even after 3months and whatever the type of sludge. The transfer of the chemical to wheat plants or to leachates was also negligible. These results are in accordance with those found in the long term field experiment where accumulation of benzo[a]pyrene is observed.

Conclusions

Impact of organic pollutants after sludge application is very dependent of the type of sludge treatment. It is also important to have a battery of bioassays in order to accurately assess agronomic efficiency and environmental impact of such solid waste. Dynamic of pollutants after sludge application, particularly plant transfer, is very dependent on the quality and quantity of organic matter of the solid waste and of the soil. Some recalcitrant organic pollutants, even present at low amount in the waste, accumulate and remain in the soil mainly as an extractable form underlying the importance to fix limits for such agricultural practices.

Acknowledgments

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Session 3:
Influence of compost and digestate
on soils properties

Influence of composts and digestates on soil properties Retrospect and outlook -

Ena Smidt¹, Katharina Meissl¹, Johannes Tintner¹, Erwin Binner¹, Peter Lechner¹.

Key words: compost properties, quality criteria, impact on soils, analytical tools

Abstract

Plaggensoil profiles were investigated to find out the long-term behaviour of compost organic matter in soils. Compost application over centuries led to an increase of organic matter in poor sandy soils. Due to the higher content of stable organic matter soil functions could be improved and led to higher crop yields in the past. Depending on land use slow transformation continues, demonstrating the strong interaction of organic matter, the soil matrix and environmental conditions.

Investigations of soil samples from asparagus fields with compost application have shown that biowaste compost with high humic acid contents could improve the organic matter content within a relatively short time. Infrared spectroscopy was used to characterize the soil and to find out the increase of humic acids in the assigned wavenumber region.

The influence of compost/ digestate organic matter on the soil matrix is discussed in the context of carbon sequestration and soil functions. Research needs are stressed.

Introduction

Composting and compost application have been performed for many centuries in order to close the loop in that organic matter and nutrients were returned to the soil. "Plaggensoils" are witnesses of the compost management that took place in the past, and of beneficial effects of composts on soils in some northwestern European countries (Germany, Netherlands, and Ireland) where poor sandy soils with low organic carbon contents (< 1 %) dominate (Springer 2001). Grass, heather and herbal waste materials were used as litter for the livestock, composted and piled up in agricultural areas where these compost layers have undergone soil formation. Despite a slow development towards the equilibrium, these anthropogenic soils still exceed organic matter and phosphate contents of the fossil horizon. In the past composting was an appropriate measure to maintain soil properties and functions. The application of mineral fertilizers has improved and accelerated plant growth which is the most apparent short-term effect. However, agricultural activities - causing turnover rates to increase - have led to organic matter degradation that is considered a serious problem in several countries (Montanarella 2002). Sanitation of degraded soils by stable organic matter is an adequate measure to fight against desertification.

The ongoing discussion about sustainable agriculture, carbon sequestration in view of global warming, recycling and bioresource management has promoted compost research and the development of adequate technologies to process biogenic materials in order to produce quality composts for specific purposes.

What are the targets to be reached? Plant growth, yields and plant health are in the focus of interest, followed by other applications such as re-cultivation and sanitation of damaged areas. The actualization of the targets in the long-term finally depends on soil properties that are preserved or improved by compost application. Therefore the maintenance of soil quality in terms of soil functions is given the top priority.

Nutrient and water holding capacity, aggregate stability and a well-balanced microbial community are strongly related to the content and the nature of organic matter in soils. Compost and digestate application contributes to the improvement of soil organic matter and increases the huge carbon pool that plays a crucial role in the global carbon cycle. It is a challenging research target to identify the different carbon pools in the soil, to evaluate their stability and turnover rates. In the context of climate change many studies in soil science focus on this topic. There are different approaches on how to provide organic matter for soil improvement. A wide range of applications, from non degraded plant materials (crop residues) to more or less stabilized composts and digestates, is practised. The effects of compost organic matter on the soil matrix and the interactions between them have not been

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understood yet. Up to now the application of composts has rather been left to practitioner's experiences.

There is no doubt that humified matter represents a stable state of organic compounds and further transformation processes take place very slowly. The biological treatment of biogenic materials anticipates the most reactive phase of degradation. It is the only biotechnological process available for synthesis of humic substances. With regard to economic considerations definition of compost quality criteria based on organic matter properties seems a realistic suggestion for the near future. There are still many questions to be answered in the field of basic research concerning interferences of compost humic substances and mineral surfaces in the soil matrix. Ongoing stabilization processes towards the equilibrium, kinetics of nutrient release and nitrogen dynamics are topics of interest for future research.

Composts intended for a specific purpose require reliable parameters to define and quantify compost quality and to identify and monitor relevant effects on soils. Suitable analytical tools for research and practical application are necessary to comply with this request. The impact of different liquid or solid substrates, originating from anaerobic and aerobic processes needs systematic investigations. The majority of studies focus on influences of compost application on plant growth and plant health. Several data of long-term field experiments reveal the effects on soils. This study focuses on the relation from experiences and knowledge from the past to targets and procedures for the future.

Materials and methods

Materials

Plaggensoil samples originating from the region Osnabrück (Germany)

"Biowaste" compost samples representing different stages of composting originating from a composting plant nearby Vienna; ingredients: yard and kitchen waste (fruits, vegetables) from the separate collection

Calcareous soil samples from asparagus fields after compost application over different periods of time

Methods

For the following investigations samples were air-dried, ground in a vibratory disk mill and screened < 0.63 mm.

Total nitrogen (TN), total (TC) and inorganic carbon (TIC) were determined by combustion in a CNS analyzer (Variomax); total organic carbon was calculated by the difference TC – TIC. Organic matter was determined by combustion in a muffle furnace at 550 °C.

Humic acids were determined according to Gerzabek et al. (1993) by alkaline extraction using 0.1 molar Na-pyrophosphate solution

Fourier Transform Infrared (FTIR) spectroscopic investigations were carried out in the KBr pellets technique in the mid-infrared area (400-4000 cm^{-1}) using the transmission mode (Infrared spectrometer Bruker Equinox 55, Germany). Two mg of the sample were mixed with 200 mg KBr (FTIR grade) and pressed to a pellet. 32 scans were recorded, averaged and corrected against air as background (Software OPUS). Data evaluation was carried out using the OPUS software.

Results

Plaggensoils – examples of the long-term behavior of compost organic matter

Organic matter contents determined as loss on ignition of several Plaggensoils (Plaggenesch) are compiled in Table 1. It is evident that organic matter contents of the "Esch" horizon (compost layers that underwent soil formation) exceed the organic matter content of the fossil horizon. Humic acid concentrations are not necessarily higher in the "Esch" horizon than in the fossil horizon.

Tab. 1: Loss on ignition (LOI) and humic acid contents of several Plaggensoils

	LOI (% DM)		HA (% ODM)	
	"Esch" horizon	Fossil horizon	"Esch" horizon	Fossil horizon
P1-En	2.2-4.7	1.9	26-61	11
P2-SC	1.3-3.9	1.0	24	22
P3-BE	3.1-3.5	1.2	23-27	n.d.
P4-GL	2.8-3.9	1.7	19-22	42
P5-LI	3.3-3.8	0.3	44-48	4

Figure 1 displays humic acid contents in the Plaggensoil profile which has been a forest area for 80 years. It is clearly visible that the content of organic humified matter increased considerably in the "Esch" horizon compared to the fossil horizon. A small layer of 2 cm at a depth of ~70 cm, rich in humic acids, can be explained by mobilization of a part of the humified organic fraction when the area was used as agricultural land. Cultivation of trees at about 1920 led to a decrease of the pH value and precipitation of humic acids took place. This example clearly demonstrates the interaction of the soil matrix and organic compounds. Sandy soils certainly represent extreme conditions regarding mobilization of water, nutrients and solved organic matter. Systematic investigations should elucidate the impact of chemical composition and texture of the soil matrix on the behavior and turnover rates of compost organic matter.

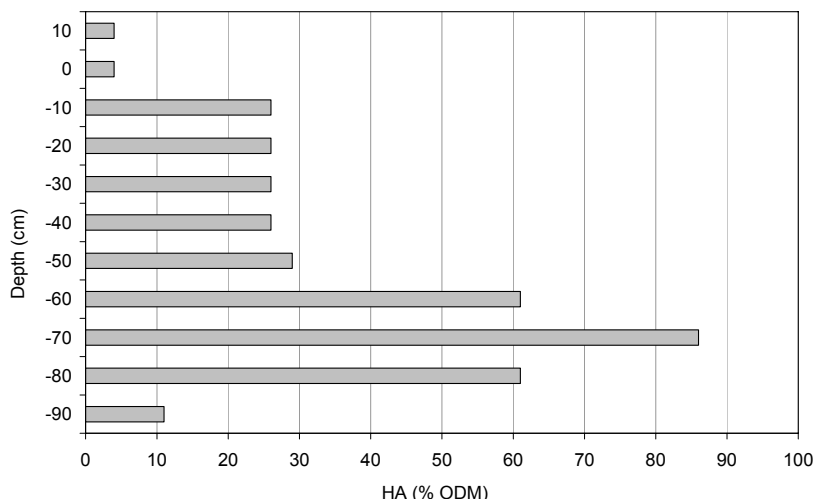


Figure 1: Humic acid contents in a Plaggensoil profile beneath forest

Nothing is known about compost quality in the past, whether composts were mature or not when they were brought to the fields. However, continuous application of these manure composts led to an increase of organic matter in the soil over the centuries. According to the historical reports farmers who carried out this kind of compost management were the richest ones in the region due to higher crop yields. The content of nutrients in the soils was obviously improved by higher organic matter contents, causing better nutrient holding capacity.

Humic substances in composts

Due to favorable properties in soils, humic substances are suitable indicators of compost quality apart from nutrients and phytosanitary effects. Humic acids that are built up during composting are an appropriate parameter to assess the quantity of stable humified organic matter in composts. Figure 2 displays the increase of humic acid contents during a composting period of 280 days.

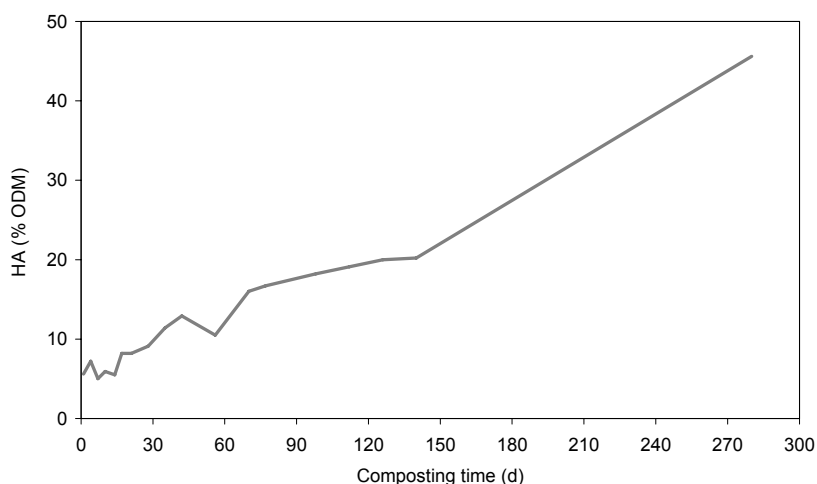


Figure 2: Increase of humic acid contents during composting of biogenic materials from the separate collection

The input material consisting of yard waste and biogenic materials from the separate collection (fruits, vegetables, plants, grass clippings, leaves) were processed in a closed system for two weeks. Then the material was composted in an open windrow system. Compared to other ones this compost yielded very high humic acid contents of 45.6 % referring to organic dry matter.

Despite the chemical extraction of humic acids that is very time-consuming, humic acid concentrations can be determined by infrared spectroscopic investigations.

Compost application in the field – a long-term study

Due to the high quality (A+ quality according to Austrian legislation) the compost was applied in a field for asparagus cultivation. The first cultivation started in 1994. Samples were taken at different sites amended with varying compost amounts over a certain period of time. Table 2 summarizes details of compost application. Agricultural activities started in 1994, compost application took place in 1999 and 2004. All fields are operated with asparagus.

Tab. 2: Compost amendment at different fields, available area, year and quantity of compost application

Sample	area	1999	2003
Soil + co 1994	1.8 ha	350 t	360 t
Soil + co 1999	1.8 ha	500 t	--
Soil + co 2004	0.77 ha	200 t	--

As shown in previous investigations humic acids are reflected in the infrared spectrum in specific wavenumber regions (Meissl et al., 2007). Figure 3 displays the whole soil spectrum (one of three references) and the selected wavenumber region assigned to humic acids. The inserted figures demonstrate the difference between the reference soil without any treatment and the compost amended soil. For each compost amended soil sample a reference sample of the untreated soil, situated next to the sampling site, was investigated. The increase of the absorption band in the soil samples with compost application over several years is clearly visible. The corresponding data of humic acid contents determined by alkaline extraction and organic matter contents are indicated in Table 3.

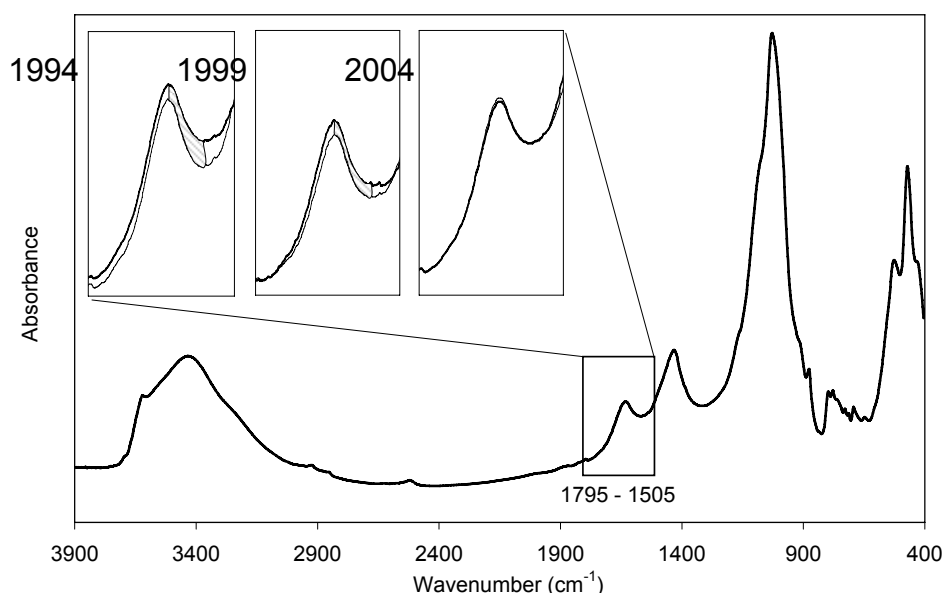


Figure 3: Infrared spectra of soil samples reflecting the increase of humic acid contents depending on time

According to the farmer's personal communication no problems regarding plant diseases have been observed since compost application. No additional amendments have been necessary.

The organic matter content (LOI) increased compared to the reference. In addition higher humic acid contents referring to organic dry matter were found in the compost treated soil.

Tab. 3: Loss on ignition, TOC, total nitrogen (Nt) and humic acid contents of soil samples after compost application (soil + co) over different periods of time

Sample	LOI (% DM)	TOC (% DM)	Nt (%DM)	HA (% ODM)
Soil + co 1994	6.2	2.6	0.27	13.7
Reference 1994	5.3	2.0	0.21	27.2
Soil + co 1999	5.6	2.1	0.22	16.5
Reference 1999	4.4	1.4	0.14	24.0
Soil + co 2004	5.7	2.0	0.18	23.2
Reference 2004	5.1	1.8	0.17	26.7

Discussion

The example of anthropogenic soils (Plaggensoils) in several regions shows impressively that improvement of poor soils regarding organic matter content is possible by continuous compost application over a longer period of time. Higher organic matter contents also affect soil functions, such as water and nutrient holding capacity, and influence therefore crop yields in a positive way. It becomes evident that interaction of organic and mineral compounds continue and that environmental conditions and land use contribute to turnover rates and dynamics of organic matter.

Field experiments could confirm that compost application over a longer period of time leads to higher organic matter contents. The compost applied featured a high content of humic acids in the final product (45.6 % ODM). The high content of stable humic acids in the compost might be the reason that an increase was observed within a relatively short period of time. Further research should clarify which stage of degradation/ humification of biogenic materials is convenient to minimize the loss of carbon and to maximize stable organic matter. Investigations of humic acids were supported by infrared spectroscopy. This analytical tool provides more comprehensive information and accelerates and facilitates humic acid analysis in practice.

The determination of the effect of organic matter improvement in soils requires detailed analyses to describe the nature of organic matter. Many studies on soil organic matter/carbon focus on their characterization by particle size or density fractionation of soil samples. Carbon stock changes under agricultural land use were monitored by adequate analytical methods (Leifeld and Kögel-Knabner 2005). The two main objectives in the research field of carbon degradation and sequestration are identification of organic matter losses in the soils (Merino et al. 2004) and control of success due to sanitation measures. Long-term field experiments were carried out at different sites (Rothamsted, Bad Lauchstädt, Germany) and provide huge data pools for model development. Apart from soil properties, climatic and many other factors, addition and removal of organic matter influence the turnover (Li et al., 1997). In most experiments manure was used as organic fertilizer. The influence of other materials and their individual properties has not been studied in detail so far. It is not clear how reactive materials interact with the mineral matrix and how mineral compounds influence transformation processes. On the one hand the stabilizing effect of mineral surfaces is well known, on the other hand mineral compounds can stimulate the turnover by influencing the pH value. Investigations of properties and behavior of organic/ humified matter at a molecular level require special analytical methods. Different approaches have been reported in literature.

Conclusions

Stable organic matter in soils is a prerequisite for favorable soil properties such as aggregate stability and porosity. Soil functions, e.g. water and nutrient holding capacity and regulation of temperature are closely related to the content of organic matter. In the context of global warming the environmental aspect of carbon sequestration in soils has to be stressed. Although degradation of organic matter and humification also take place in natural processes, the preference should be given to the controlled composting process under optimized conditions with regard to process operation, environmental protection and defined product quality. Future research will focus on the definition of "final products" and quality criteria. More detailed investigations are necessary to find out the well balanced mixture of ingredients and appropriate process operation to achieve a certain product quality for specific purposes. This procedure will establish the basis for marketable products. Finally the effects on soils should be investigated properly on the molecular level to understand the interactions between compost/ digestate organic matter and the soil matrix. Carbon fixation and release, nutrient holding capacity and nutrient availability for plants, nitrogen dynamics, influence of composts/ digestates in the soil on the microbial community and phytosanitary effects are issues that have top priority.

Acknowledgments

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Influence of mid-term application of composts on chemical, physical and biological soil properties of agricultural soils in field trials of practical importance

Rainer Bolduan¹, Berthold Deller¹, Rainer Kluge¹, Markus Mokry¹, Holger Flaig¹

Key words: Compost application, soil improvement, fertilization efficiency, sustainable crop production, humus balance

Abstract

Mid-term field experiments (over 12, resp. 9 years) with compost application at (6-7 t/ha/y dry matter resp. 20 t/ha every three years) above all contribute positively to the OM (humus) reproduction of the soil positively influencing the humus balance and the soil structure/soil water household. Beneficial effects are also observed for soil biology (microbial activity) and the nutrient status. Fertilization effects are also evident (marginally for nitrogen), particularly with phosphorus and potassium to be accounted in the nutrient balance and thus standing for limiting factors for compost application. A conservation liming can also be reached. The comprising benefits gradually show in better yields and improved soil fertility on appropriate sites. On the long run, the soil improving effects are of higher significance than the fertilization effects.

Introduction

The presented investigations on agricultural compost application over a period of 12, resp. 9 years were performed within the frame of a joint research-project of the German Environmental Foundation and a follow-up project of the LTZ Augustenberg. The comprising goal was the deriving of application guidelines for the sustainable use of quality controlled composts in agricultural crop production. Referring to this, the LTZ was responsible for the investigation of possible benefits and risks.

Objectives of the compost application trials are to get experience on

- optimal compost amounts/application rates for crop production
- the accountability of compost nutrients as well as further nutrients in the fertilization balance
- soil physical and soil biological effects
- the impact on heavy metal and organic pollutant contents in soil and harvest products.

Materials and methods

The chemical, physical and biological impacts of mid-term compost application on five field trials of practical importance performed on mostly clayey and loamy soils under participation of the cultivating farmer and the local composting plant were examined on soil and plant samples. The experimental design was a randomized bi-factorial combination of compost variants (0, 5, 10 and 20 t DM/ha) with supplementary nitrogen fertilization (without, 50 % and 100 % of recommended nitrogen fertilization) on a unique crop rotation of corn/winter wheat/winter barley. All applied composts were quality assured and specified.

Results

As the mid-term experiments show, the humus contents increased with optimal compost application rates of 2,5 - 3,0 t/ha*yr dry matter by 0,2 - 0,6 % in course of the trials and about 0,02 - 0,05 %/year. The concomittant liming effect stabilises and increases the pH value slightly, respectively. With optimal compost rates about 2 - 4 dt/ha*y CaO are supplied in average. The nutrient supply is in average about 40 - 50 kg/ha P₂O₅, 60 - 80 kg/ha K₂O und 45 - 60 kg/ha MgO (P and K are fully accountable). Therefore, the direct N fertilisation effect is very small, as proven clearly by field experiments. During the first 3 years only 3 - 5 % of compost N can be accounted for the fertilisation effect after application. With ongoing regular application of composts (5 - 10 years) about 8 - 10 %, (max. 15 %) of the total N supply can be estimated as directly available every year.

Concerning the soil physics and soil biology, the following results could be observed: An increase of soil aggregate stability, a reduction of the bulk density, an increase of field capacity and an

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enhancement of the moisture infiltration. A promotion of the microbial soil activity could also be detected.

Discussion

Average compost applications of 20 t/ha dry matter (31 t/ha fresh matter) within a three years period resp. annually 6-7 t/ha DM (9 -11 t/ha fresh matter) have been proved as an optimised regime in agricultural plant production. With these quantities a good nutrient and organic matter (OM) balance is normally achieved and thus the concept of sustainability is fulfilled with the application of compost.

The high portion of stable forms of reproduction-effective carbon is of determining importance as part of the compost organic matter, which leads to a sustainable humus reproduction in the soil. Particularly, the humus build-up contributes to a substantial soil improvement. (leading to a reduced erosion potential; enhancement of aeration, drainage and water storage, improvement of trafficability). Besides, there is scientific evidence of promoting the soil biological activity leading to better site conditions for crop production. The N supply by compost is only of minor influence on the fertilization, because the organically bound nitrogen has mobilised at very low rates. The strong organic N sorption prevents unexpected N-mobilisation events and leaching into the groundwater. With regular control measurements of the soil nitrate and a reduced mineral N- fertilization at ca. 10 - 15 % such risks could be excluded effectively, as shown by the field experiments.

The efficiency of the application of composts results always as **sum of all particular effects**. Therefore composts are to be classified as organic NPK fertilizers.

Conclusions

Composts will be more and more acknowledged and appreciated for their combined effect as valuable humus and nutrient suppliers in crop production. Above all the supply of organic resources for a sustainable humus reproduction of arable land will become increasingly important. This development is accelerated through increasing sales of straw to the industry and the increasing market of biomass for renewable energy production. In regions with highly intensified agricultural production (e.g. commercial farms without husbandry, crop rotations with high humus consumption) problems of a negative humus balance can thus be avoided.

Given a proper quality management (including a monitored hygienisation), the high portion of stable humus forms and the highly efficient phosphorus and potassium fertilisation effect, composts are usually superior to other secondary raw materials used as organic amendments (e.g. digestion residues from biogas plants, liquid manure, untreated plant residues). In addition, the potential negative impacts associated with the use of composts constitute a calculable risk respecting a precautionary concept of long term soil management and pose no problems for the environmental safe utilization of quality assured compost. It can be stated that composts of assured quality fulfil the requirements of a sustainable cycling of organic materials in an optimal way regarding ecologic and economic aspects on appropriate sites.

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Use of Compost to Improve Soil Properties and Plant Growth in Saline Soils

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Key words: Compost, Saline Soil, Industrial Effluent, Vetiver

Abstract

Pot and field trials demonstrated that compost use was able to improve properties of acidic saline soil irrigated with industrial effluent, and enhance growth of moderately salt-tolerant plants (corn, sorghum, E. punctata) even in extremely saline soil.

Introduction

Salinity represents a major land degradation problem in many low rainfall areas with high evaporative demand. The most widespread causes of salinity are the replacement of deep-rooted native vegetation with shallow rooted agricultural crops (dry land salinity) and large-scale agricultural irrigation, both of which result in rising water tables that transfer salts to the soil surface. Use of low quality irrigation water, including industrial effluent, is also a common cause of soils becoming saline.

Adverse chemical and biological conditions in saline soils usually impact negatively on plant growth and crop yield. If salinity is combined with sodicity, declining soil physical structure can result in water logging and further yield reduction. As compost is known to be able to improve soil chemical, physical and biological properties, pot and field trials were conducted to determine whether the use of compost could improve soil properties and plant growth in saline soils.

Materials and methods

Two types of compost were used in pot and field trials to improve soil properties and plant growth in an acid (pH 5.0) cracking clay (Vertosol) with high nitrate concentrations and medium to high salinity. Salinity in this soil was largely caused by ten years of irrigation with industrial effluent, which is high in sodium, chloride, sulphate and nitrogen (pH 7.6, EC 8.1 dS/m). The soil was amended with increasing rates (v/v) of either low nutrient compost (C-1) made from garden organics, or high nutrient compost (C-2) made from gelatine manufacturing residues. High electrical conductivity (EC) in compost C-2 (17.9 dS/m) was caused mainly by excessive ammonium concentrations (2,224 mg/kg), not elevated sodium or chloride. Forage sorghum (*Sorghum bicolor*), corn (*Zea mays*) and Vetiver grass (*Vetiveria zizanioides*) was used as test plants in pot trials, which were watered either with industrial effluent or deionised water. While only topsoil (A-Horizon) was used in the first pot trial, the second trial aimed at reflecting natural growing conditions by placing sub-soil (B-Horizon) in the bottom of pots (depth 7 cm), overlain with compost-amended topsoil (depth 10 cm).

Field trials were conducted at highly saline land irrigated with industrial effluent. In the first field trial Vetiver grass was planted after amending the topsoil with 0, 10, 27, or 108 t dm/ha of either of the two composts C-1 or C-2. In the second field trial *Eucalyptus punctata* was planted (1m x 3m) after applying 4L or 12L of compost (C-1 or C-2) per tree in the rip line. This trial was replicated on a well-drained, moderately saline soil.

All EC values for soil and compost were determined in a 1:5 water extract.

Results

In the first pot trial, addition of compost increased pH values from 5.0 to levels that are more favourable for agricultural crops (pH 5.8 – 7.2). However, increasing compost amendments also increased salinity levels. 50% of C-1 compost raised EC_{1:5} values up to 1.75 dS/m, and 50% of C-2 compost to 3.26 dS/m. While de-ionised water changed growing media properties very little, the use of effluent further increased salinity levels to between 3.4 and 7.9 dS/m at the end of the trial period. Soil salinity ratings consider EC_{1:5} levels >0.9 dS/m as 'high' and levels >2.0 dS/m as 'very high' (Shaw, 1988). This means that many growing media (soil plus compost) used in the trials showed high or very high salinity levels. Use of effluent for irrigation also raised chloride and nitrate levels sharply.

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The use of 10%, 25% and 50% (v/v) compost C-1 in soil with medium salinity increased vegetative sorghum yield by 41%, 62% and 90%, respectively, while compost C-2 improved yields by 17% and 33% at the two lower application rates and reduced yield by 5% at the highest rate. Compost use resulted in significantly improved plant growth even in very saline conditions ($EC_{1:5}$ 2.5 – 7.9 dS/m). Yields were similar in un-amended, moderately saline soil ($EC_{1:5}$ 0.3 – 0.4 dS/m), and in effluent irrigated, highly saline soil ($EC_{1:5}$ 2.8 – 6.0 dS/m) that was amended with 25% and 50% compost C-1.

Amendment of topsoil with compost C-1 at 10%, 20%, 30% and 50% (v/v) in the second pot trial also raised pH, while it decreased $EC_{1:5}$ from 1.8 dS/m to as low as 1.35 dS/m when 50% compost was added. Compost use increased chloride and potassium levels somewhat. Addition of compost increased emergence of corn from 37.5% to between 50% and 62.5% and subsequent plant yield was increased by between 24% and 104%. It was interesting to note that water use efficiency (g of water used per g of plant fresh matter) improved between 32% and 54% where the soil was amended with compost. Despite improving various soil characteristics, compost use failed to significantly improve growth of Vetiver grass in saline soil. Nevertheless, improved water use efficiency was also observed in this trial, although at a lower level than was observed for corn.

The promising pot trial results could not be replicated in field trials. Although high compost application rates (108 t dm/ha) increased pH from 4.14 to 4.37, this effect disappeared during the 11-month trial period, as did the observed increased salinity ($EC_{1:5}$ 2.06 dS/m) caused by compost C-2 at the highest rate. The use of compost did not change any other chemical soil properties significantly. Potential yield differences for Vetiver grass could not be determined due to uneven planting.

However, in the second field trial, Eucalyptus trees responded favourably to compost C-1. In highly saline soil ($EC_{1:5}$ 1.3 dS/m, pH 4) high application of compost C-1 resulted in increased tree growth (18%), and in moderately saline soil ($EC_{1:5}$ 0.15 – 0.3 dS/m, pH 4.1 – 4.6) the low compost application rate generated taller trees (10%) during a seven month growing period.

Discussion and conclusions

The trials demonstrated that compost use is able to improve soil properties and plant growth in saline soil. Highly saline soil amended with high rates (25 and 50%, v/v) of low nutrient compost (C-1) generated as much plant growth, as did moderately saline, unamended soil. High nutrient compost (C-2) did not perform as well, despite low sodium and chloride concentrations. It appears that less salt tolerant plants (corn, sorghum, *E. punctata*) benefited more from compost use than salt tolerant plants (Vetiver grass).

Compost use does not reduce salinity, except for possible dilution effects, and does also not solve the underlying cause of the salinity problem. However, the use of compost on saline soils still improves the establishment and growth of plants. Therefore, compost use can offer a short-term reprieve for farming on soils with medium to high salinity, or soils with temporary high salinity (dry period). The results suggest also that high application of compost may be a very useful tool for ameliorating severely salt affected areas through the establishment of plant cover, including deep-rooted trees that help lowering the water table.

Irrigation with industrial effluent resulted in soil properties that are unique and not representative of most typical saline soils. Therefore, the conducted trials should be replicated with soils that resemble dry land salinity and 'normal' irrigation salinity. Nevertheless, watering of trial plants with industrial effluent demonstrated that compost use is able to aid plant growth in extremely saline conditions.

Acknowledgments

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Long-term effects of biowaste compost fertilization on crop yield and nutrient supply, soil humus and nitrogen leaching

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Key words: biowaste compost, nitrogen recovery, carbon sequestration, phosphorus, potassium

Abstract

The effects of biowaste compost fertilization as compared to mineral fertilization and no fertilization have been investigated in a field experiment near Vienna since 1992. The yields in the compost treatments increased for 7 – 10 % compared to the unfertilized control and the nitrogen recovery by crops was between 3 and 7 % of the total nitrogen applied in the compost treatments. Phosphorus and potassium supply with compost fertilization was approximately as high as with mineral fertilization. Nitrogen leaching to the groundwater as determined using ceramic suction cups was not increased with compost fertilization as compared to mineral fertilization. The humus content of the soil increased from 3.4 % to 3.5 – 3.7 % in the compost treatments, indicating that 10 – 19 % of the organic carbon applied via compost was stored in the soil.

Introduction

Organic materials make up a large part of the municipal waste stream. Recycling of organics through composting and using of biowaste compost in agriculture may contribute to closing again the natural ecological cycles. The 'STIKO' field experiment was started in 1992 at the Obere Lobau near Vienna in order to investigate the effects of fertilization with biowaste compost on the yield of the agricultural crops and on the environment.

Materials and methods

The 'STIKO' experiment included three treatments with biowaste compost fertilization (8, 15 and 22 t ha⁻¹ yr⁻¹ (fresh matter) on average of 13 years), three treatments with mineral nitrogen fertilization (26, 41, and 57 kg N ha⁻¹ yr⁻¹ plus 41 kg ha⁻¹ P₂O₅ and 74 kg ha⁻¹ K₂O), five treatments with combined fertilization and an untreated control in six replications in a latin rectangle design. Individual plots measured 6.3 x 10 m. The biowaste compost used was produced at the composting plant of the City of Vienna in an open windrow process from source separated organic household waste and yard trimmings. The soil on the site is a Molli-gleyic Fluvisol, average annual temperature was 10.4 °C, average annual rainfall 542 mm. The crop rotation included 75 % cereals and 25 % potatoes. Except for the fertilization, the trial is managed according to the EU regulation 2092/91 on organic farming with customary farm machinery. In 1996, the field experiment was complemented by a lysimeter station consisting of three monolithic lysimeters with lysimeter plots and of six plots of the ongoing field experiment which were equipped with probes and ceramic suction cups. Further details on the methods used were given by Erhart et al. (2005; 2007), and Hartl and Erhart (2005).

Results and Discussion

The yields in the compost treatments increased for 7 – 10 % compared to the unfertilized control. On the fertile experimental site, the yield response to the compost applications was low in the beginning, but increased with the duration of the experiment. The yields of the mineral fertilizer treatments were somewhat lower than the local average, because also in this treatments no stem stabilizer was used in cereals. Similarly moderate yield increases with compost fertilization were reported from several field experiments in Germany. In our experiment, the low yield response may be attributed to some extent to the dry climatic conditions at the experimental site, which do not favor compost mineralisation.

The nitrogen recovery by crops was between 3 and 7 % of the total nitrogen applied in the compost treatments. In the treatments with combined fertilization, 2 – 6 % of the nitrogen applied via compost was found in the plant offtake. The total nitrogen content of the soil increased significantly in the compost treatments during the experiment, while it remained more or less unchanged in the treatments with mineral fertilization. At the same time, compost fertilization raised the soil C_{org}-levels, indicating that a large part of the N_{tot} applied via compost is tied up in soil organic matter.

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Plant phosphorus and potassium contents showed that the phosphorus and potassium supply with compost fertilization was approximately as high as in the mineral fertilizer treatments. Plant available soil contents of potassium, but not of phosphorus, increased significantly in the treatment with the highest compost rate as compared to the treatments with mineral fertilization. Total soil phosphorus and potassium showed a trend towards increased concentrations in the topsoil. Thus, phosphorus and potassium in biowaste compost are nearly as well available for plants as in mineral superphosphate or triplephosphate fertilizer and in mineral potassium magnesia fertilizer, respectively, and can, therefore, be fully included in the fertilizer calculation.

Nitrogen leaching to the groundwater as determined using ceramic suction cups was not increased after 11 years of compost fertilization as compared to mineral fertilization. Even intensive nitrogen mineralization during a four month period of bare fallow did not cause pronounced differences in nitrogen leaching between the fertilization treatments. The nitrogen leaching data confirm the results of the residual nitrate-N measurements in the soil profile at the end of each growing season, which were in the same range for both compost and mineral N fertilization.

The humus content of the soil decreased markedly in the unfertilized control of the experiment from 3.4 % to 3.15 %, although the straw was left on the field in nearly all years. The total carbon loss accounted for 6,250 kg C ha⁻¹, which is an annual loss of 0.85 % of the soil humus. The humus contents of the compost treatments on the contrary increased to 3.5 - 3.7 %. Compost fertilization with 8 t ha⁻¹ yr⁻¹ resulted in a slight increase of the humus content as compared with the level at the start of the experiment. With higher compost rates, the increase of the humus level was more pronounced and statistically significant. Mineral fertilization was sufficient to maintain the initial humus level due to increased plant biomass. In the soil of the compost treatments, between 1,900 and 6,500 kg ha⁻¹ organic carbon were stored, which corresponds to 10 – 19 % of the organic carbon applied with the compost.

Conclusions

Nitrogen fertilizer value and yield increase through compost fertilization were moderate on the experimental site, a fertile Molli-gleyic Fluvisol in the pannonic climate. Phosphorus and potassium in biowaste compost, however, are nearly as well available for plants as in mineral phosphate and potassium fertilizer, respectively, and may therefore fully substitute these. Groundwater quality was not affected by compost fertilization. Compost application led to a significant increase in soil humus content, which does not only benefit soil fertility, but also represents medium-term carbon sequestration, which might contribute to climate protection.

Acknowledgments

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Effects of repeated municipal waste compost fertilizations on soil and plants in a crop rotation field experiment in Finland

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Key words: biowaste, sewage sludge, nutrients, trace elements, faecal coliforms, N mineralization

Abstract

A 6-year crop rotation field experiment on fine sandy moraine was fertilized 3 times with waste composts (municipal biowaste, biowaste + sewage sludge, cattle manure). Nutrients, trace elements, hygiene indicators and microbiological activity were measured to evaluate the effects on soil and yields. Soil quality was not decreased and soil nutrient contents were not changed by municipal waste composts. Most compost treatments increased the yields during the application year when compared to unfertilized yield.

Introduction

The basic principles of waste legislation include waste prevention, increasing the utilization of waste and decreasing the detrimental effects caused by waste. The EU directive on the landfill of waste (1999/31/EC) advises the member states to increase the recycling and utilization of bio-degradable waste for example by composting or anaerobic digestion. Both of these produce organic and nutrient-rich material with highly variable state of decomposition, which can be applied as fertilizing or soil improving material in agriculture. The benefits and potential detrimental effects of repeated applications of municipal waste composts were studied in Finnish agricultural field conditions.

Materials and methods

The field experiment was established in 2000 in Juva, central Finland (61°40'N, 27°13'E, fine sandy moraine) with a split-plot design with four replications having application level (low / high / zero-control) in the main plot and compost type (Biowaste B / Biowaste+Sewage sludge BS / CattleManure CM) in the sub-plot. Tunnel-composting facilities supplied good-quality waste composts for the experiment. The 6-years of crop rotation included; cereal nurse crop – grass-clover – grass-clover – barley – potato – cereal nurse crop. Compost fertilization was given in spring 2000, 2004 and 2005 for both cereal nurse crops and potato with applied amount of compost defined according to national N or P fertilizing recommendations. Samples of compost and soil were taken in spring immediately before the application. Soil samples were taken also in autumn, hygiene samples of soil 2 weeks after compost spreading and plant samples at harvesting. Total and soluble concentrations of nutrients and trace elements were determined from the samples of compost, soil and plants (total), by either international standard methods or national methods. As one of the determined indicators of hygiene, the faecal coliforms were analyzed from compost samples and from the soil samples of “high” application level and non-fertilized zero control. Microbial activity of soil was studied from autumn samples, including the net N mineralization from anaerobic incubation.

Results and discussion

The applied amounts of composts were 9-45, 3-9 and 23-52 t/ha in 2000, 2004 and 2005, respectively. The amount of total N allowed in the EU nitrate directive was exceeded in many cases, as the corresponding amounts of total N supplied in composts were 127-712, 37-119 and 194-693 kg tot N/ha. Less than 13% of compost total N was in soluble form in all 3 spring applications of compost, whereas the average proportion of soluble N was less than 9% of total compost N (Tab. 1). When applied according to P fertilization in 2000, B compost supplied higher amount of soluble N than other composts. The contents of trace elements and the amounts applied in B and BS were higher than those in CM compost. However, the contents were below the current national limits. Only Cu and Zn in the waste composts exceeded the EU limits for household compost applied in organic production.

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Tab. 1: Average chemical characteristics of the experimental compost types.

Average contents in composts	Total nutrients (g/kg DM)			Soluble nutrients (g/kg DM)			Trace elements ⁽⁵⁾ (mg/kg DM)							
	N ⁽¹⁾	P ⁽²⁾	Org.C ⁽¹⁾	N ⁽³⁾	P ⁽⁴⁾	K ⁽⁴⁾	As*	Cd	Cr	Cu	Hg	Ni	Pb	Zn
CattleManure	27	6	444	2.0	3.6	29	0.7	0.09	5	21	0.07	4	4	104
Biowaste	29	8	313	2.2	1.6	6	4.1	0.33	34	66	0.17	13	21	175
BioSludge	28	16	292	2.5	0.3	3	3.7	0.51	41	120	0.31	17	20	305

⁽¹⁾ N, C; dry combustion (Leco), ⁽²⁾ wet combustion, ⁽³⁾ soluble N=ammonium (NH₄-N) + nitrate (NO₃-N), KCl extraction, ⁽⁴⁾ soluble P and K; AAAC extraction, ⁽⁵⁾ trace elements from AR extraction (*As from wet combustion).

The highest amounts applied were 4.2 kg/ha for Cu and 10.2 kg/ha of for Zn, and the soil Cu and Zn contents mainly decreased during the experiment time (Tab. 2). The initial Zn contents of soil were different between low and high application level in spring 2000, and this difference remained unchanged after 3 compost fertilizations. The final state of soil Cu and Zn was within the range Mäntylähti & Laakso (2002) found in the same region, although higher than their average content in the agricultural field soils. Total nutrient contents in soil were not altered by compost fertilizations, whereas CM increased soluble K content of soil. Yields of cereal nurse crop were increased by compost fertilizations when compared with zero control, whereas grass-clover and potato yields were not increased after compost applications.

Although wastes were carefully composted, both B and BS composts contained more faecal coliforms than CM compost. Hygiene quality of composts was improved during the experiment. Two weeks after compost application in 2004, the highest amount of faecal coliforms was found in the unfertilized zero control soil (2400 cfu/g), probably due to faeces of wild birds. At the same time, there were less than 500 cfu/g of faecal coliforms found in soil after the high compost application. Both BS_{high} and CM_{high} increased the net N mineralization in soil after three compost fertilizations when compared with the zero control, averaging 64, 66 and 49 µg N/g/7d, respectively. At low application level of composts the N mineralization averaged 56 µg N/g/7d. Probably the repeated compost fertilizations did increase soil N reserves potentially available to microbes (Debosz et al. 2002).

Tab. 2: Initial and final contents of Cu and Zn in soil and amounts applied in composts.

	Copper (mg/kg DM soil) ⁽¹⁾			Zinc (mg/kg DM soil) ⁽¹⁾		
	2000 spring	2005 autumn	applied ⁽²⁾	2000 spring	2005 autumn	applied ⁽²⁾
Zero control	22	21	0	71	66	0
CattleManure _{low}	22	28	0.5	74	67	2.6
Biowaste _{low}	23	21	1.6	74	66	4.2
BioSludge _{low}	22	21	2.1	80	73	5.1
CattleManure _{high}	22	21	1.0	93	86	5.1
Biowaste _{high}	21	21	3.1	93	81	8.3
BioSludge _{high}	22	21	4.2	86	78	10.2

⁽¹⁾ Cu and Zn from AR extraction. ⁽²⁾ Sum of Cu (kg/ha) and Zn (kg/ha) added into soil in 3 compost applications.

Conclusions

Based on trace element contents, indicators of hygiene and microbiological activity, we found no decrease of soil quality due to waste compost fertilizations. Some waste composts could even increase soil activity. During compost application year the yields were often increased with compost fertilization compared to unfertilized yield. Utilization of composts could partly compensate for the use of mineral fertilizers and at the same time restore soil organic matter withdrawn by the crop.

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Session 4.1:
Influence of compost and digestate
on plant growth and health

Influence of compost and digestates on plant growth and health: potentials and limits

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Key words: compost quality, plant growth, soil fertility, plant health

Abstract

Composts can influence soil fertility and plant health. These influences can be positive or negative, depending of the quality of the composts. In order to estimate the potential of Swiss composts to influence soil fertility and plant health, one hundred composts representative of the different composting systems and qualities available on the market were analyzed.

*The organic substance and the nutrient content of the composts varied greatly between the composts; the materials of origin were the major factor influencing these values. The respiration rate and enzyme activities also varied greatly, particularly in the youngest composts. These differences decreased when the composts become more mature. Maturity, the degradation stage of the organic matter, depended not only on the age of the compost, but also on the management of the process. The N-mineralization potential of compost added to soil showed that a high proportion of young composts immobilized the nitrogen in the soil. Two compost parameters allow to predict the risk of nitrogen immobilization in soil: the NO₃⁻ and the humic acids contents. The phytotoxicity of the composts varied very much even in mature composts, showing that the storage of the compost plays a decisive role. While the majority of composts protected cucumber plants against *Pythium ultimum*, only a few composts suppressed *Rhizoctonia solani* in basil. With respect to disease suppression, the management of the maturation process seems to play a major role.*

In field experiments, some biologically immature composts immobilized nitrogen in soil and reduced growth of maize. With additional fertilization, however, it was possible to compensate this effect. Digestates and composts increased the pH-value and the biological activity of soil. These effects were observable also one maize season after compost application.

In conclusion, big differences were observed in the quality of composts and digestates, and in their impact on soil fertility and plant health. The management of the composting process seems to influence the quality of the composts to a higher extent than the materials of origin or the composting system. More attention should be paid to biological quality of composts, in order to produce composts with more beneficial effects on crops.

Introduction

Composts and digestates can influence soil fertility and plant health. These influences can be positive or negative, depending of the quality of the products and on their utilization. Inadequate management of the composting process may result in composts containing plant pathogens, weed seeds or toxic compounds which can cause damage to the crops. In contrast, well-managed composts can have the capacity to stimulate plant growth and to protect crops against diseases. While a lot of work has been done with only few composts, little is known on the quality spectrum of the different composts produced, and of their different influences on plant growth and plant health.

In order to estimate the potential of Swiss digestates and composts to positively influence soil fertility and plant health, one hundred composts and digestates representative of the different composting and methanization systems were analyzed. In addition to the characterization of quality of the different products, two field experiments were performed to evaluate the short term influence of composts and digestates on soil fertility and plant growth.

Materials and methods

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Samples from one hundred and one composts and digestates were collected from different composting and methanization plants according to the guidelines and recommendations with respect to waste fertilizers (FAC 1995). The product description is according to ASCP Guidelines 2001 (Fuchs et al., 2001). All plants process only source-separated organic material. The samples were chosen in such a way that they are representative of the composts produced in Switzerland. The samples were either tested immediately after collection, or stored at 3°C until testing.

Nutrients and heavy metals were analyzed with ICP-AAS according to the official Swiss methods (Schweizerische Referenzmethoden, 2005).

Humic acids were determined according to Gerzabek et al. (1993) by alkaline extraction using 0.1 molar Na-pyrophosphate solution.

The influence of compost on nitrogen mineralization in soil was determined with the incubation experiment according to the official Swiss methods (Schweizerische Referenzmethoden, 2005). Five to 10 percent of compost was added to a reference soil, placed in PVC boxes (12 x 10 x 5 cm, with aeration holes), wetted and incubated at 25°C. The mineralized nitrogen (NH₄ and NO₃) in the soil was determined after 0, 2, 4, 6 and 8 weeks.

The activity of four enzymes was determined: fluorescein diacetate according to Inbar et al. (1991), dehydrogenase, protease and cellulase according to Alef and Nannipieri (1995).

The phytotoxicity tests were performed according to Fuchs and Bieri (2000). In the open phytotoxicity tests, the growth of cress (*Lepidium sativum* L.), salad (*Lactuca sativa* L.) and bean (*Phaseolus vulgaris* L. var. *nanus* L) in pots (Ø 10 cm) filled with compost was compared with the growth in reference substrate BRS-200 (Biophyt Ltd, CH-Mellikon). In the closed phytotoxicity test, PVC boxes (1 liter) were half-filled with compost or reference substrate BRS-200, cress sown onto it, then the boxes were closed hermetically. The growth of the plants in the boxes was then observed.

Two disease suppressivity tests were performed: cucumber (*Cucumis sativus*)-*Pythium ultimum* and basil (*Ocimum basilicum*)-*Rhizoctonia solani*. Both tests were performed in 200-ml plastic pots. Compost (20 % v/v) was added to the soil. In the cucumber-*Pythium* test, the pathogen was grown for 7 days on autoclaved millet, and then added to the soil. In the basil-*Rhizoctonia* test, the pathogen was also grown on millet which was placed on the bottom of the pots before the plants were sown. Damping-off of the cucumbers was evaluated 10 to 15 days after sowing. In the basil-*Rhizoctonia* test, the living plants were counted after one, two and three weeks.

Two field experiments were performed in maize: in 2004, the experiment was made in a loamy soil and 2005 in a sandy soil. Digestates and composts were applied in the spring before the maize was sown (100 m³ per ha). Eight weeks after sowing, N_{min} and plant height were measured. At harvest, total yield was determined. After harvest, soil samples were taken and analyzed chemically and biologically.

Results

Chemical characteristics of the Swiss composts

The chemical characteristics of the different products are presented in tab. 1. The values for the different composts varied greatly. The contents of salts, nitrogen, phosphorus, potassium, magnesium and calcium depends predominantly on the materials of origin. The organic matter and the density are mainly influenced by the maturity of the products. However, high variability was observed for all parameters within a product category. For example, the salt content, which should be low in the composts for covered cultures and private gardening, varied between 328 and 1539 [g KCL equivalent / 100 g fresh matter]. Through a more consistent choice of the materials of origin, the compost producers could obtain a more constant salt content in the final product.

Tab. 1: Chemical characteristics of Swiss composts¹

	Digestate for agricultural use ²	Compost for agricultural use ²	Compost for horticultural use ²	Compost for covered cultures and private gardening ²
salt content ³ [mg KCl/100g FM] median (minimum; maximum)	970 (704; 1384)	862 (361; 1580)	787 (173; 2657)	660 (328; 1539)
pH ³ median (minimum; maximum)	8.5 (8.0; 8.8)	8.2 (7.5; 8.7)	8.1 (7.6; 8.7)	7.9 (7.2; 8.5)
density [g/l] median (minimum; maximum)	468 (321; 631)	556 (412; 851)	609 (434; 836)	715 (631; 904)
dry matter [% FM] median (minimum; maximum)	53.1 (45.4; 75.2)	50.8 (28.2; 73.4)	56.7 (40.8; 71.1)	56.3 (32.2; 64.5)
organic matter [% DM] median (minimum; maximum)	50.3 (28.9; 73.4)	47.7 (17.0; 80.1)	38.1 (23.9; 54.7)	30.6 (20.9; 52.8)
total N [g/kg DM] median (minimum; maximum)	15.3 (9.4; 20.3)	16.6 (8.7; 26.0)	14.6 (9.2; 27.6)	15.1 (8.6; 25.2)
total P [g/kg DM] median (minimum; maximum)	3.6 (2.0; 8.0)	3.0 (1.7; 6.1)	3.0 (1.3; 12.7)	3.3 (2.1; 8.8)
total K [g/kg DM] median (minimum; maximum)	12.5 (6.4; 20.8)	12.0 (5.7; 25.2)	11.6 (2.2; 20.7)	10.7 (5.5; 27.8)
total Mg [g/kg DM] median (minimum; maximum)	6.8 (3.7; 9.7)	4.8 (3.6; 10.3)	6.5 (4.4; 10.7)	6.5 (4.4; 13.3)
total Ca [g/kg DM] median (minimum; maximum)	46.6 (23.0; 57.8)	53.1 (24.0; 83.7)	64.0 (35.0; 91.5)	44.5 (69.4; 29.5)
Fe [mg/kg DM] median (minimum; maximum)	8.9 (3.7; 12.3)	8.8 (2.9; 16.7)	10.1 (5.4; 14.7)	12.0 (6.1; 15.8)

¹ according to the "Guidelines and Recommendations of the Research Centre for Agricultural Chemistry and Environmental Science with respect to waste fertilisers" (FAC 1995).

² product description according to ASCP Guidelines 2001 (Fuchs et al., 2001)

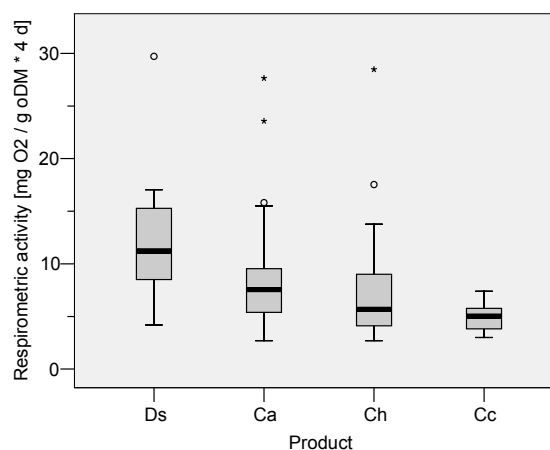
³ value determined in 1:2 water extract

Characterisation of the biological activities of the Swiss digestates and composts

Respiration rate decreased with compost maturation (fig. 1), as already shown by different authors (Paletski and Young, 1995; Lasaridi and Stentiford, 1998; Popp et al., 1998). Interesting to notice is the reactivity of digestates, which show a very intensive biological activity as soon as they are coming in contact with oxygen. This reactivity of digestates can also be observed by the enzymatic activities of the products (fig 2). However, the evolution of the activity of four enzymes during composting differed greatly (fig. 2). The FDA (fluorescein diacetate activity) and the protease activity differed significantly between the different product classes (fig. 2). Their activities are decreasing with the advancement of product maturity. A similar evolution, but less evident, is observable in the cellulase activity. By contrast, the dehydrogenase activity was less influenced by the maturity of the products.

Figure 1. Respirometric activity of Swiss composts. Products according to ASCP Guidelines 2001 (Fuchs et al., 2001).

Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.



Influence of composts and digestates on plant growth

Plants react on compost or digestate quality as a whole. Sometimes, all of the above-mentioned chemical parameters of a compost are good, but plants do not develop well in it for unknown reasons. To assess this risk, the phytotoxicity tests are used. The four phytotoxicity tests used react differently to compost quality. The open cress test is the least sensitive, and the plants showed growth depression only in the digestates (fig. 3Co). The open lettuce test is more sensitive, and only the more mature products allowed a good growth of the plants. In the closed cress test, the plants are not only in contact with the compost, but are also strongly influenced by the gases which evaporate from the compost. This test is therefore very sensitive, and only composts with high plant compatibility allowed a good growth of the cress (fig. 3Ccl).

Digestates are generally less compatible with plant growth than composts. In all test systems, an evolution in the plant compatibility was obvious, with the plants growing better in more mature composts (fig. 5). Nevertheless, there was considerable variation within a product class. This fact shows that the management of the composting is at least as important for the biological quality as the maturation advancement.

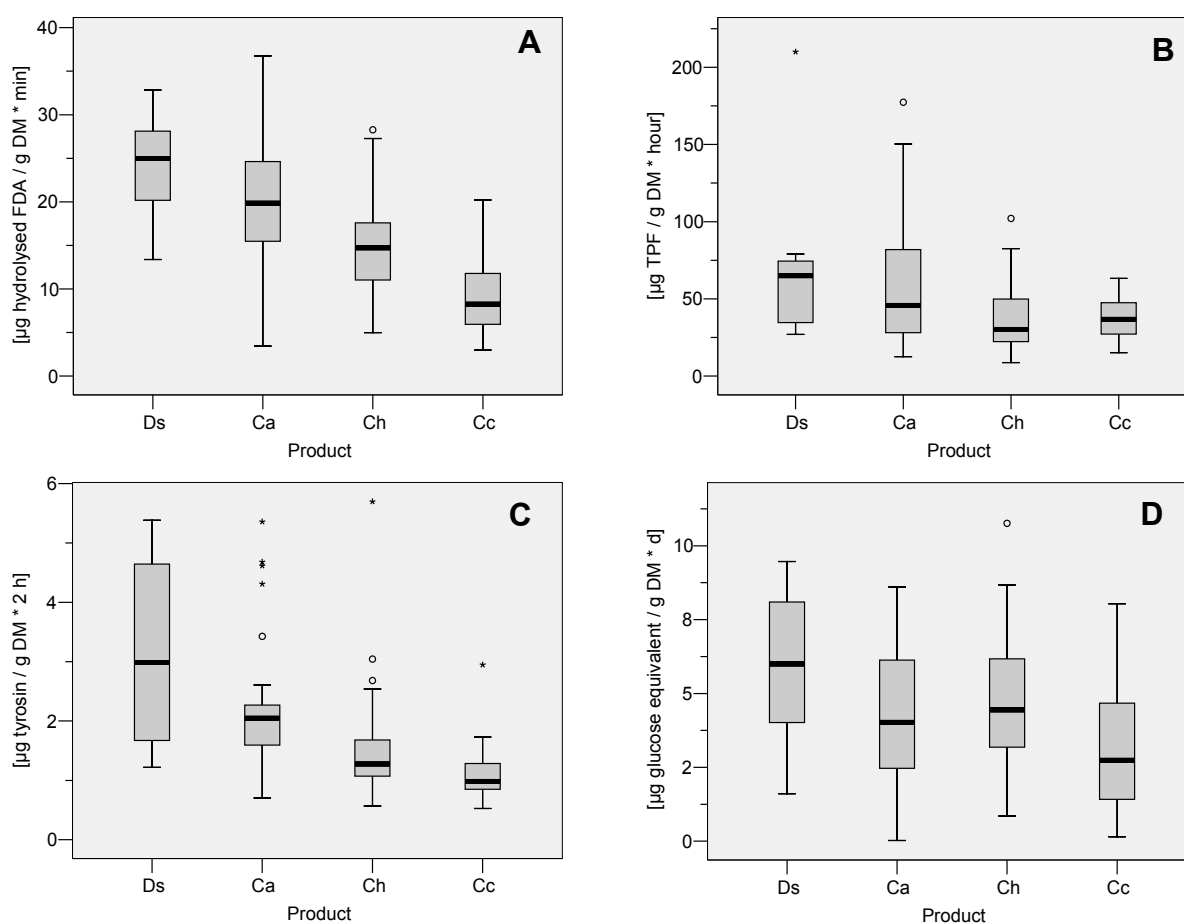


Figure 2. Enzymatic activities of Swiss composts. A: FDA activity; B: dehydrogenase activity; C: protease activity; D: cellulase activity.

Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Capacity of Swiss composts and digestates to protect plants against soil borne diseases

The suppressive potential of the composts against two pathogens was tested: *Pythium ultimum* and *Rhizoctonia solani*. *P. ultimum* causes damage mainly during germination. *R. solani* can attack the plant later and cause important damage also to larger plants.

The great majority of the composts significantly reduced the incidence of *P. ultimum* on cucumber. No differences were observed between the products of the different classes (fig. 4P). The protection of basil against *R. solani* was clearly less efficient (fig. 4R). It seems that the capacity of the composts to protect basil against *R. solani* reached a maximum at the stage Ch (fig. 4R). In agreement with other

authors, we assume a general protection mechanism for *P. ultimum* and a specific mechanism in the case of *R. solani* (Hoitink et al., 1997; Fuchs, 2002, Fuchs and Larbi, 2005).

In both cases, there was large variability within the product classes. This indicates that the management of the composting process is a major factor influencing the suppressive capacity of the composts.

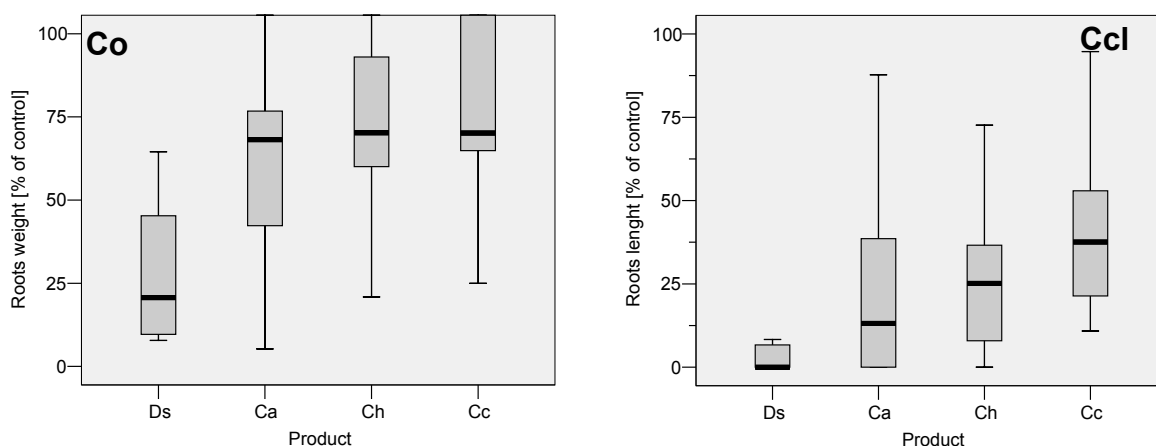


Figure 3. Phytotoxicity of Swiss composts, determined with the open (Co) and closed (Ccl) cress biotest.

The growth of plants in pots filled with compost was compared with the growth of plants in reference substrate (Co, S and B). Products were sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

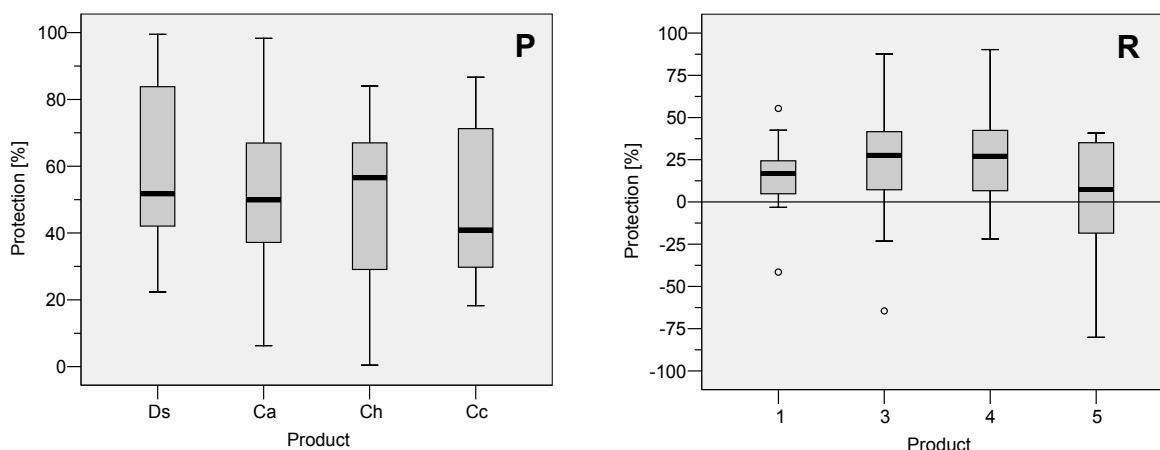


Figure 4. Capacity of Swiss composts to protect plants against soilborne diseases.

P: protection from cucumber against *Pythium ultimum*; R: protection of basil against *Rhizoctonia solani*. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Influence of digestates and composts on the mineralized nitrogen content of soils

The mineralized nitrogen in soil greatly influences plant growth. The influence of compost on the mineralized nitrogen content in soil depends, beyond the quantity of available nitrogen, also on the microbiological activity of the compost. Normally, digestates contain a high amount of mineralized nitrogen, mainly as ammonia, and they contain relatively low quantities in the form of lignin rich materials. Therefore, nitrogen immobilization is not expected after the utilization of such products. In our experiments, this was not always the case (fig. 5Ds). The reason for the immobilization of nitrogen in soil by some digestates is that these products are not used fresh, but after an inadequate subsequent treatment, during which the digestate has been dry and has lost all the ammonia.

In the other products, the evolution of the nitrogen immobilization risks can be clearly observed (Fig. 5). The composts for agricultural use are mainly young composts rich in undegraded lignin. The

degradation of these woody substances in soil leads to a momentary immobilization of the available nitrogen (Fig 5Ca). When the composts were more mature, this risk decreased (fig. 5Ch and 5Cc).

Two compost parameters allowed to predict the risk of nitrogen immobilization with compost: the nitrate and the humic acids contents. As soon as the nitrification process began and nitrate was present, the composts did not immobilize nitrogen in the soil (fig. 6). Further, no relevant nitrogen immobilisation was observed with composts with a content of humic acids higher than 130 [mg / g oDM] (fig. 6).

Application of Swiss digestates and composts in the field

Two field experiments were performed in 2004 (loamy soil) and 2005 (sandy soil). Digestates and composts were applied in the spring before a maize crop. After harvest, soil samples were taken and analyzed.

The four composts for agriculture tested immobilized nitrogen in soil and had a negative influence on maize growth at the beginning of the culture (fig. 7). These results confirm the results obtained in the laboratory: compost with almost no $\text{NO}_3\text{-N}$ Nmin and with humic acids contents lower than 130 [mg / g oDM] immobilized nitrogen also in the field (tab. 2). Notice that this point is relevant only for compost, and not for digestates (tab. 2). Nitrogen fertilization after 8 weeks (at the moment of the observations of fig. 7) allows correcting the nitrogen deficiency, so that at harvest no significant differences in the yield of the different treatments were observed (data not shown).

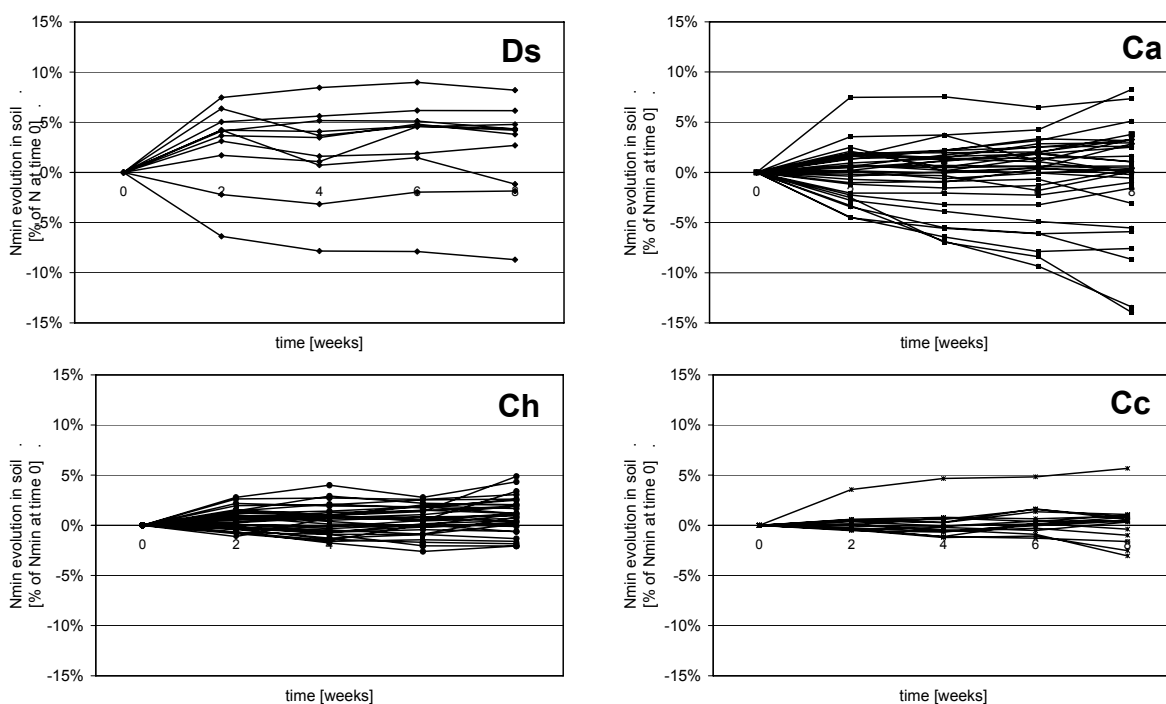


Figure 5. Influence of the addition of different composts to soil on the evolution of its mineralized nitrogen content.

For each compost, the mineralized nitrogen after 2, 4, 6 and 8 weeks are compared to the mineralized nitrogen present in the soil immediately after compost addition. Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

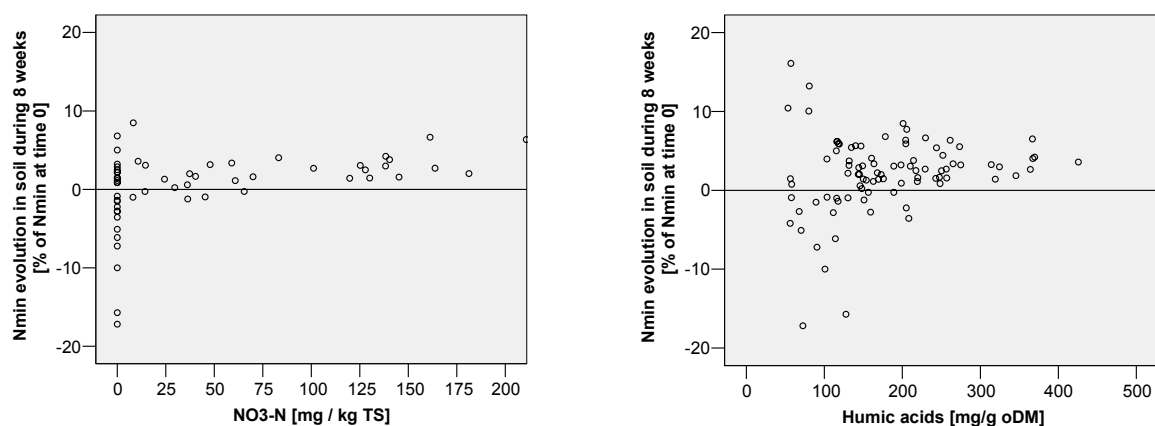


Figure 6. Relation between the evolution of mineralized nitrogen content in soil and nitrate content (left) and humic acids content (right) of compost.

For each compost, the mineralized nitrogen during 8 weeks is compared to the mineralized nitrogen present in the soil immediately after compost addition.

The digestates and the composts enhanced the soil pH for about 0.5 units (fig. 8). This effect is still observable after the harvest of maize. All the products enhanced also the biological activity in the soil. However, no influence could be observed on the disease receptivity of the soil. The enhancement of the pH did not correspond exactly with the Ca content of the composts, although in 2004 the two composts with the greatest quantity of calcium caused the highest rise of the soil pH (tab. 2)

Table 2. Calcium contents, pH, nitrogen characteristics, FDA-activities and humic acids content of the digestats and composts used in the fields experiments

Compost	Ca [g / kg DM]	NH ₄ -N [mg / kg DM]	NO ₃ -N [mg / kg DM]	N-supply or immobilization in soil during 8 weeks ¹ [% of Nmin at time 0]	FDA activity [µg hydrolysed FDA / g DM*min]	humic acid content [mg / g oDM]
Field experiment 2004 (loamy soil)						
Digestate						
D1	46.6	606.7	260.7	-2.2	23.4	67.9
D2	65.2	1980.1	0.2	16.1	20.3	57.1
Compost for agriculture						
Ca1	68.4	35.9	0.2	-5.1	17.6	70.3
Ca2	49.7	66.8	0.2	-7.2	20.6	90.7
Compost for horticulture						
Ch1	81.5	4.4	65.4	-0.3	14.0	189.1
Ch2	64.3	119.8	267.7	2.7	14.1	364.1
Compost for covered cultures						
Cc1	91.5	4.5	45.3	-1.0	8.8	130.3
Cc2	63.7	10.0	59.0	3.4	15.9	163.7
Field experiment 2005 (sandy soil)						
Digestate						
D1	38.4	398.4	480.9	0.8	25.1	58.1
D2	152.3	1821.9	0.0	10.5	13.4	53.5
Compost for agriculture						
Ca1	39.4	19.3	0.0	-17.2	25.2	72.5
Ca2	58.2	132.2	0.0	-10.0	6.5	100.9
Compost for horticulture						
Ch1	65.7	0	366.1	5.5	10.6	273.4
Ch2	65.5	6.6	215.4	3.4	8.2	265.1
Compost for covered cultures						
Cc1	65.5	0.0	234.9	2.1	3.0	144.9
Cc2	60.8	9.6	363.8	4.4	6.8	252.0

¹ Incubation experiment by 25°C

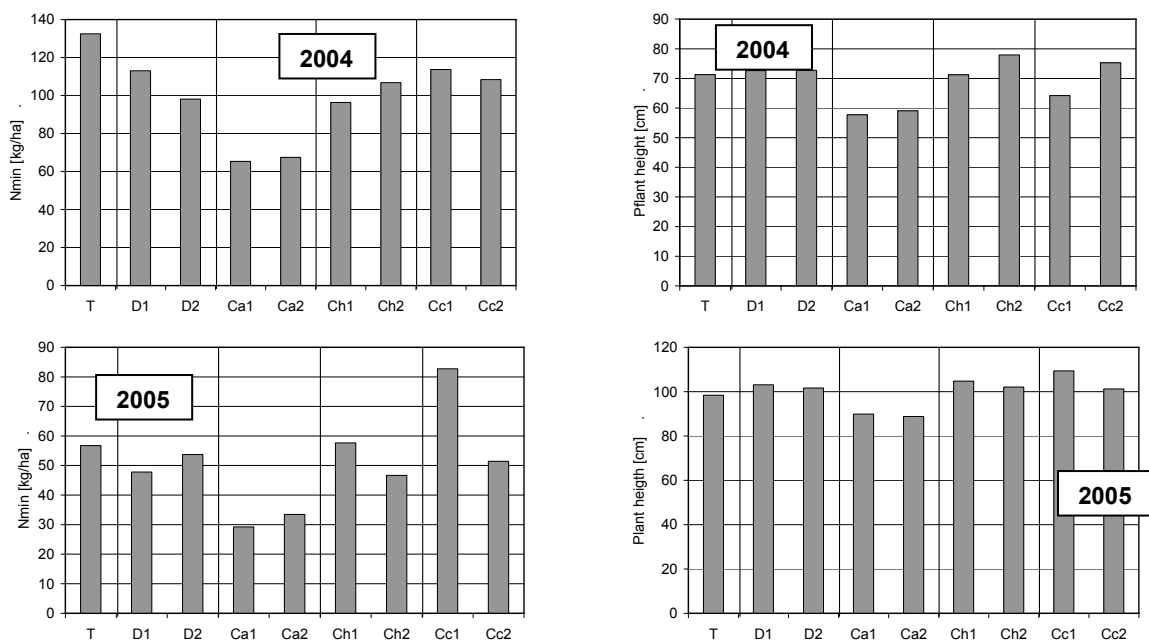


Figure 7. Influence of application of digestates and composts on the mineralized nitrogen content in soil and on the growth of maize. Application of 100m³/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 8 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost; D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

To characterize the biological activity of the soil, its enzymatic FDA activity was investigated after the maize harvest. Almost all digestates and composts increased the FDA activity between 10 and 30% (fig. 9). This shows that compost and digestate have a prolonged effect on the biology of the soil. The biological activity of the soil was not correlated with the biological activity of the compost or digestate applied (tab. 2). So it is probable that activity the soil microorganisms is enhanced by compost amendment, and that the activity of the compost microorganism are not responsible for the observed enhanced enzymatic activities in the soil after the maize harvest.

The influence of digestates and composts on the receptivity of soil to diseases was investigate with the two pathosystems cucumber / *Pythium ultimum* and basil / *Rhizoctonia solani*. No influence of digestates or composts could be observed on the disease receptivity of the soil after one maize season (data not shown)..

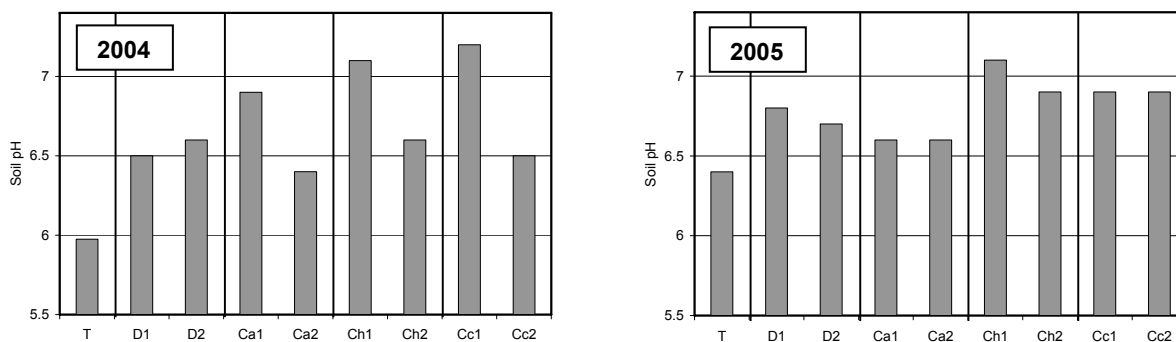


Figure 8. Influence of application of digestates and composts on the pH of the soil. Application of 100m³/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 6 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost, D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

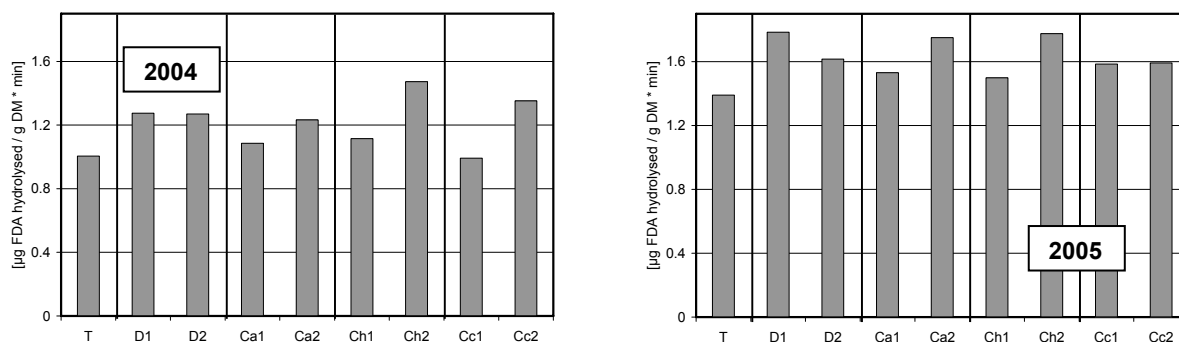


Figure 9. Influence of application of digestates and composts on the microbiological activity of the soil. Application of 100m³/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 6 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost; D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Conclusions

In general, it was observed that the quality of the Swiss composts is good. No major problems were observed in any sample. One important reason for this is that only source separated organic materials are composted. Nevertheless, the characteristics of the different digestates and composts vary in an important way. Some parameters like the nutrient contents, the heavy metal contents and the salinity are influenced principally by the materials of origin. Other parameters like density, organic matter, enzymatic and respirometric activity and phytotoxicity are principally influenced by the maturity of the products. The potential for nitrogen immobilization is affected by maturity, by the composition of the composted materials and by the management of the composting process. The major influence of the biological quality of the composts (phytotoxicity and suppressive potential) seems to be due to the management of the composting process.

The differences observed between the different composts indicate clearly that the choice of the right compost for the envisaged utilization is very important. The results confirm that the four product classes proposed in Switzerland are useful for practice (solid digestate (Ds), compost for agricultural use (Ca), compost for horticultural use (Ch), compost for covered cultures and gardening (Cc)). They should be refined for some parameters, for example for the nitrogen immobilization potential. This is a very important parameter for the compost users, and this characteristic can show large variation especially in digestate and young composts. Field experiments carried out in the last two years show that the incubation tests presented here correlate very well with the performance of maize in the field (data not shown). More attention should be given to nitrogen immobilization, particularly when compost is used in spring.

In the field experiment, the digestates and composts showed very interesting effects on the soil pH and on the microbiological soil activity after one season of maize. These effects were observed in fields managed with good agricultural practise and with good fertility potential. Bigger effects are likely in fields with structural or fertility problems.

Acknowledgments

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Compost: a Promising Vehicle for the Inoculation of PGPR in Agricultural Soils?

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Key words: compost, PGPR, Biolog EcoPlate™

Abstract

Aim of this work was to evaluate the possibility of using a compost as vehicle for the inoculation of the plant growth promoting rhizobacteria (PGPR) *Pseudomonas fluorescens* 92. To assess its survival in compost and soil, the strain was tagged with the green fluorescent protein gene (*gfp*). *P. fluorescens* 92^{Rgfp} survival was evaluated in compost, in agricultural soil added with compost and in soil. The influence of total humidity on strain survival was also assessed. Viable counts of *P. fluorescens* 92^{Rgfp} and total counts of mesophilic bacteria were weekly determined up to one month. In parallel, a community-level physiological profiling of the indigenous microflora was carried out. *P. fluorescens* 92^{Rgfp} viability drastically decreased 7 days after inoculation in all treatments. The strain survived until the end of the experiment in compost and in soil added with compost at 20% total humidity while in soil alone and in compost at 40% humidity it only survived until the 14th day. Total bacterial counts remained stable throughout the experiment both in inoculated and non-inoculated treatments. The community-level physiological profiling revealed a decrease of the metabolic activities in the inoculated soil and soil plus compost vs. the non-inoculated.

Introduction

Current agricultural practices emphasize on environmental sustainability by encouraging both the use of soil bio-amendments as promising alternatives to minimize the deleterious effects of chemical fertilizers and the application of plant growth-promoting rhizobacteria to enhance crop yield. However, the key to achieving successful, reproducible results following the introduction of beneficial microbes into soil relies on the survival rate of the inoculated bacteria in a heterogeneous soil environment. In this work, a compost has been used as vehicle for the inoculation of the PGPR *P. fluorescens* 92. The strain was chosen owing to its phosphate-solubilizing activity, indol-acetic acid and siderophores production and plant promoter activity in glasshouse and in *in vivo* experiments (Gamalero *et al.*, 2003; Fracchia *et al.*, 2008).

Materials and methods

A rifampicin resistant *P. fluorescens* 92 strain was tagged with the *gfp* gene by conjugation with the tetracycline resistant strain *Escherichia coli* S17-1(Apir):pUT-mini-Tn5-gfp-Tc. The marked strain, hereafter named *P. fluorescens* 92^{Rgfp}, was cultivated on Luria-Bertani agar added with rifampicin and tetracycline (25 µg ml⁻¹). As bacterial inoculum vehicles, argentinean compost derived from urban wastewater sludges and agricultural soil (Argiudol) were used. The experiments were conducted in microcosmos conditions at different total humidity (Th) (20% and 40%). The following treatments were prepared in duplicate: compost, soil added with 6% compost, soil. Microcosmos were inoculated with a concentrated culture of *P. fluorescens* 92^{Rgfp}. Controls consisted of non-inoculated treatments. Viable counts of *P. fluorescens* 92^{Rgfp} and total mesophilic bacteria were weekly determined as CFU g⁻¹ d.w. up to one month. Community-level physiological profiling was studied by means of Biolog EcoPlate™ at day 3 and 7 of incubation; samples inoculum and readings were carried out according to Harch (Harch *et al.*, 1997).

Results

P. fluorescens 92^{Rgfp} maintained the PGPR characteristics such as siderophore, indol-acetic acid production and phosphate-solubilization. In survival experiments, *P. fluorescens* 92^{Rgfp} viability drastically decreased (2-3 logs) 7 days after inoculation in all the treatments. In compost samples at 20% Th and in soil added with compost, the strain viability kept stable until the end of the experiment with counts respectively of 3.8 x 10² CFU g⁻¹d.w and 8,9 x 10¹ CFU g⁻¹d.w. In compost treatments at 40% Th and in soil, the strain survived only until day 14. Total bacterial counts remained stable

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throughout the experiment both in inoculated and non-inoculated treatments, ranging between 10^7 - 10^8 CFU g⁻¹d.w. The community-level physiological profiling revealed a decrease of the metabolic activities in the inoculated soil and soil added with compost vs. the non-inoculated ones. In particular, the differences were related to the use of eight carbon sources.

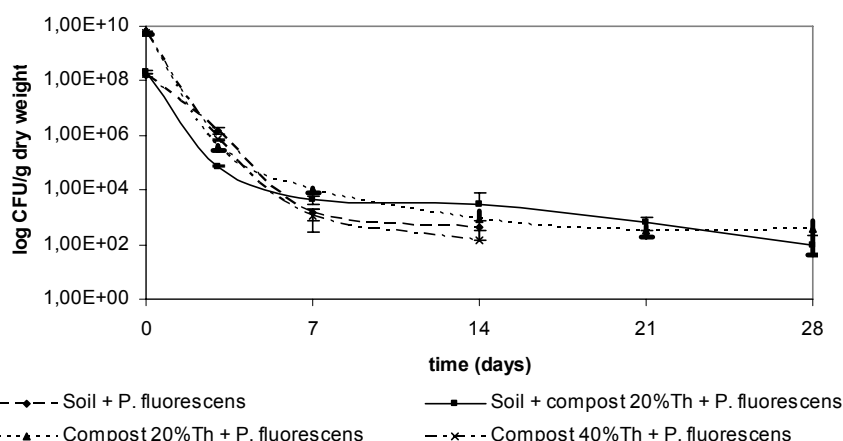


Figure 1: *P. fluorescens* 92^{RTcgfp} viability in compost at 20% and 40%Th, in soil and soil added with compost

Discussion

P. fluorescens 92^{RTcgfp} showed a good survival in compost while in soil it seemed to be suppressed. These results suggest that compost may have a protective effect toward the strain as confirmed by the fact that when *P. fluorescens* 92^{RTcgfp} was inoculated in soil through compost its survival was extended until the 28th day. Moreover, the results underline the importance of total humidity for strain survival. Concerning physiological profiling, the decrease of the metabolic activities of the total microflora in inoculated compost and soil added with compost may be related to a competition effect for some substrates due to the presence of the high concentration of *P. fluorescens* 92^{RTcgfp}.

Conclusions

Our results indicate that compost may be, under controlled condition (e.g. total humidity), a potential vehicle for PGPR inoculum in agricultural soils. In any case, further analysis have to be undertaken in order to clarify the effect that the PGPR inoculum has on the physiological profiling and on the composition of the compost and soil autochthonous microflora.

Acknowledgments

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Crop nitrogen utilisation: source separated green/food compost

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Keywords: compost, nitrogen, soil quality, nitrate leaching

Abstract

A series of experiments in England to evaluate the beneficial effects of green/food compost (derived from source separated green and food 'waste') on crop available nitrogen (N) supply and soil quality/fertility is described in this paper. Results from the first year of the study showed that green/food compost application in autumn 2005 to a sandy soil did not increase ($P > 0.05$) over-winter nitrate leaching losses. The fertiliser N replacement value of the green/food compost applications at the three experimental sites was in the range 9-21 kg N/ha (mean = 13 kg N/ha), with associated N utilisation efficiencies in the range 3-8% of total N applied (mean = 5%). The study will continue for a further two years to measure compost N supply to following crops and effects on soil quality and fertility.

Introduction

The largest volume market in the UK for the recycling of composted green 'wastes' has been assessed to be in agriculture, with an arable landbank of approximately 5 million hectares. Green composts contain potentially valuable amounts of nutrients and organic matter. Hence, the recycling of composts to agricultural land could be of benefit to soil quality, fertility and crop yields, as well as enabling recycling targets to be met.

Nitrogen (N) is an essential constituent of plant proteins and both crop yields and quality can be markedly reduced if insufficient supplies are provided. It is important to predict crop N requirements accurately from both economic and environmental reasons. Hence, the effects of using compost as a source of crop available nitrogen requires evaluation. Similarly, as soil quality benefits are likely to develop gradually over a period of time and will vary with soil and climatic conditions, measurements undertaken after repeated applications are most likely to detect changes.

This paper describes a series of experiments being conducted in England which are designed to evaluate the beneficial effects of green/food compost (derived from source separated green and food 'waste') on crop available N supply and soil quality/fertility.

Materials and Methods

Experimental field studies were established in autumn 2005 at three sites in England on contrasting soil types. At each site, replicated experimental treatments were established consisting of green/food compost, inorganic fertiliser N dose-response treatments and an untreated control. Following compost application and soil incorporation, all the experimental plots were sown with winter wheat. Recommended rates of inorganic P, K, Mg and S fertilisers were also applied to ensure that crop yields were only limited by the nutrient being studied (*i.e.* nitrogen). Grain yields and nutrient offtakes were measured at harvest in 2006. Over-winter (2005/06) nitrate leaching losses were measured from green/food compost and an untreated control treatment at the Gleadthorpe site (a sandy textured soil), using porous ceramic cup samplers (Webster *et al.*, 1993). Water samples were analysed for nitrate-N ($\text{NO}_3\text{-N}$) and N leaching losses calculated using drainage volumes estimated by 'Irriguide' (Bailey & Spackman, 1996).

Results and Discussion

The application of green/food compost did not increase ($P > 0.05$) over-winter nitrate-N losses, with total N losses of c.16 kg/ha and average $\text{NO}_3\text{-N}$ concentrations of c.18 mg/l on both treatments (Table 1).

Tab 1: Nitrate leaching losses at ADAS Gleadthorpe over-winter 2005/06; standard errors in parenthesis.

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Treatment	Total N loss (kg/ha)	Average NO ₃ -N concentration (mg/l)
Untreated control	16.0 (2.9)	18.4 (3.4)
Compost	15.9 (4.3)	18.3 (4.5)

The application of green/food compost (at c.250 kg total N/ha) resulted in small (< 1 t/ha), but non-significant ($P > 0.05$) increases in grain yields at all 3 sites. The grain yield response to increasing rates of inorganic fertiliser N was described by a linear plus exponential function ($\text{yield} = a + br^N + cN$), with r fixed at 0.99 (George, 1984). Using the grain yield and fertiliser N response function, fertiliser N replacement values and N utilisation efficiencies of the compost applications were calculated (Table 2).

Tab 2: Fertiliser N replacement values (kg/ha) and N utilisation efficiencies (%); standard errors in parenthesis.

Site	Total N applied (kg/ha)	Fertiliser N replacement value (kg/ha)	Utilisation efficiency (% total N applied)
Gleadthorpe (Notts.)	274	10 (4.0)	4 (1.1)
Boxworth (Cambs.)	294	9 (3.5)	3 (1.1)
Rosemaund (Here.)	266	21 (8.0)	8 (3.0)

Fertiliser N replacement values and N utilisation efficiencies were similar at all 3 sites ($P > 0.05$) at means of 13 kg/ha (range 9-21 kg N/ha) and 5% (3-8%), respectively (Table 2). Hence, the majority of the total N applied in the compost was not available for crop N uptake and as a result grain yields were only elevated to a small extent above the untreated control treatment. Grain N offtakes showed a similar trend to grain yields, with no differences ($P > 0.05$) in N offtake as a result of compost application at any of the sites.

Conclusions

There were no differences in over-winter nitrate-N leaching losses (compared with an untreated control) following the application of green/food compost in autumn 2005 on the sandy textured soil at ADAS Gleadthorpe. The fertiliser N replacement value of the green/food compost applications at the three sites was in the range 9-21 kg N/ha (mean = 13 kg N/ha) and N utilisation efficiency in the range 3-8% of total N applied (mean = 5%).

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Control of *Rhizoctonia solani* in potatoes with a new application technique of suppressive composts in organic potato production

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Key words: suppressive compost, agricultural engineering, *Rhizoctonia solani*, organic potatoes

Abstract

The suppressive effect of composts to control *Rhizoctonia solani* in potatoes was tested in organic field trials at the University of Kassel in 2006 and 2007. As composts we used yard waste alone and a mixture of organic household and yard waste. The composts were directly placed near the seed tubers with a rate of 5t dm/ha with a strip application technique. Seed tubers (variety Nicola) naturally infested with three levels of black scurf were planted. The rate of initial infection and compost amendments had a strong impact on symptoms of *R. solani* on harvested tubers in both years. Across all initial infection classes compost amendments reduced the infestation of harvested potatoes with black scurf by up to 50% resulting in 15-25% higher marketable yields depending on year and compost used.

Introduction

Since the use of organic seed potatoes has become compulsory in organic potato production, black scurf (caused by *Rhizoctonia solani* Kühn) is increasing in importance. Currently, no convincing control strategies for the disease are available. As the pathogen is as well soil as seed tuber borne both inoculum sources need to be considered when approaching the problem

Compost application leads to sustained increase in microbial activity and the establishment of microbial populations with antagonistic features (Hoitink und Boehm 1999) and promising results have been obtained with suppressive composts against several soil-borne pathogens. Tsrör et al. (2001) and Lootsma (1997) already demonstrated that it might be possible to control *R. solani* with composts in practice. However, we have shown that good effects are generally dependent on the amount of applied compost material (Bruns und Schüler 2002). To reduce the total amount of compost needed, our study aimed at testing if the targeted application of limited amounts of compost near the seed tubers can reduce the total amount needed. We are also working on the development of an application system. Field trials were conducted to evaluate a compost application system with row application during planting of potatoes for its suppressive effects.

Materials and methods

A two-factorial field trial was performed as split-plot design with four replications (at the experimental farm of University of Kassel in Witzenhausen on a silty loam with 74 soil points according to the German system).

Factor A: Compost application 5t DM*ha⁻¹. In 2006 and 2007, a 5 month old compost made of organic household waste-/ yard waste (60/40), composted according to German regulations (BGK 1998) was used. In 2007, in a second compost treatment, a 15 month old yard waste compost was used. In both years, control plots without compost received an N,P,K –nutrient-equivalent to the household/yard waste compost nutrient load. The composts were directly applied at the seed tuber area using a modified fertiliser application machine (*Universal Kastenstreuer, UKS 150, Fa. Rauch, Sinzheim*).

Factor B: Infection severity of seed tubers. Seed tubers (variety Nicola) naturally infested with black scurf were planted in three infection classes (no = <1%, middle 2-5% and high infection > 10% of surface area). Seeding date was 04.05.2006 and 18.04.2007. All assessments were performed according to the EPPO – standard PP 1/32 (2). Several harvests were performed with three rows with 6,7m length each: (harvest 1: two weeks after dying off at 11.9.06 and at 30.08.07 (results in this paper show only data from harvest 1). Statistical analysis was based on the SPSS GLM procedure (version 12), means were separated according to Bonferroni-Holm ($p \leq 0,05$).

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Results and Discussion

Both, initial infection and compost amendments significantly affected final infection levels and marketable yields (Tab. 1 and 2). Composts reduced the infestation of harvested potatoes with black scurf by a mean of 20% and the rate of tubers with deformations and dry core by 45%, on average, at final harvest (Tab. 1). Application of the household/yard waste compost increased marketable yields by 17 to 42% in the two years while the older yard waste compost in 2007 resulted in increases of 11-15% (Tab. 2). In terms of farmers' income this would mean an increase of the proceeds of up to 2000€/ha. Preliminary data on microbial activity indicate that the main impact of compost application is in the phase of potato emergence. Probably, there is also a strong interaction between quality of organic matter of the composts and soil microbial life.

The results indicate that there is a need to develop a strip application technique for composts for control of the disease.

Tab. 1: Severity of *R. solani* and percent deformed potatoes (% of gross yield) after compost application and in dependence of seed tubers infestation with *R. solani*

	Black scurf severity on harvested tubers			Factor Mean compost	deformed potatoes (% gross yield)			Factor Mean compost
	< 1%	2-5%	> 10%		< 1%	2-5%	> 10%	
seed-tuber infection	< 1%	2-5%	> 10%	Factor Mean compost	< 1%	2-5%	> 10%	Factor Mean compost
with compost	2.04	2.85	3.03	2.64 a	7.75	14.75	14.75	12.42 a
without compost	2.82	3.30	3.78	3.30 b	15.75	20.75	32.25	22.92 b
Factor Mean seed tuber infection	2.43 a	3.07 b	3.40 c		11.75 a	17.75 b	23.5 c	

Tab. 2: Marketable yield of potatoes (t/ha) (<15% black scurf, no deformation) after compost application and in dependence of seed tubers infestation with *R. solani*

	marketable yield 2006				Factor Mean compost	marketable yield 2007			Factor Mean compost
	< 1%	2-5%	> 10%	Factor Mean compost		< 1%	2-5%	> 10%	
seed-tuber infection	< 1%	2-5%	> 10%	Factor Mean compost	< 1%	2-5%	> 10%	Factor Mean compost	
with compost A	25.26	22.72	20.34	22.77 a	20.88	16.45	13.94	16.82 a	
with compost B					18.59	15.86	13.11	15.76 a	
without compost	21.55	18.59	14.33	18.16 b	16.80	14.05	11.44	14.09 b	
Factor Mean seed tuber infection	23.41 a	20.66 b	17.34 c		18.49 a	15.36 b	12.83 c		

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Effects of vermicompost-tea on plant growth and crop yield

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Key words: vermicompost, compost tea, plant growth, DGGE, microbial community

Abstract

Vermicompost was used to produce elutriates (aerated compost teas) containing micro-organisms together with all soluble nutrients from the compost. Micro-organisms growth was actively influenced during the extraction process by substrate addition. Teas of different production procedures have been analysed by chemical, microbiological and molecular biological (DGGE) methods accompanied by plant growth tests in laboratory scale. A slight change in micro-organism population in soil and an increased plant growth were determined as effect. The optimised tea was applied to cereals (wheat and barley) and vegetables (radish, rucola and peas) in field studies as well as to tomatoes under greenhouse conditions. The soil was investigated during the experiments to detect microbial or chemical changes. Plants were monitored during vegetation to compare plant growth and health, finally, crop yields were determined. The results for all field experiments showed only marginal differences, more often in plant quality than in quantity.

Introduction

Generally, compost elutriate (compost tea) is produced by putting a defined quantity of compost into water and mixing it for a definite time (Scheuerell, 2004). Actively aerated compost teas with additives are recommended to be produced (Ingham, 2006) expected to enhance the growth of beneficial and suppress pathogenic micro-organisms.

During the brewing process, micro-organisms and also all soluble nutrients of the used compost are extracted into the tea which could be applied directly on soil or by spraying on the plant foliage. Applied to the soil, the tea will go towards the roots, thus nutrients can be used by the plant and the micro-organism population of the rhizosphere could be (positively) affected (Bess, 2000). It is probably an interaction of several factors (mineral nutrients, micro-organisms, plant growth regulators) which result in an improved plant growth after the application of vermicompost teas (Edwards et al., 2006).

There are only a few scientific papers about this topic which are also controversial. That is the reason why we investigated compost tea production and the effect on plants in detail.

Materials and methods

Compost teas were produced in an extraction vessel in the scale of 850 litres from 10 litres compost.

Several physical and chemical parameters were determined after the tea production and during the elution process every 6 hours. Microbial (total and fungi-CFU), respiration rate and molecular biological analyses (DGGE) were analysed from final teas, were further processed by calculation of the Shannon-Weaver diversity index (Brodie, 2003) and evaluated by cluster analysis.

Plant growth test with cress and tomatoes were performed in an air-conditioned room. Applied tests included radish, rucola and peas in small field areas at the institutes own site (applied as foliar spray) and tomatoes under greenhouse conditions in a partner institute (applied to soil). Yield quantity was determined by weight, quality either as visual appearance of the plants or by taste of the harvest.

Results and Discussion

Production conditions did influence the chemical and microbiological composition of the final tea (Table 1). Since no other quality criteria had been defined before, those teas with the highest count of micro-organisms and the highest diversity in the microbial population were selected for the following plant tests. A tea produced by sequential extraction of vermicompost followed by an addition of green leaf compost and sunflower press cake was identified to support plant growth in laboratory experiments better than other recipes and was used for all further experiments.

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Table 1: Selected results of vermicompost-teas produced under different conditions.

Production additive	E _{485nm} (colour)	NO ₃ [mg/l]	K [mg/l]	P [mg/l]	Fungi (CFU/ml)	Bacteria (CFU/ml)	Shannon- index b.
polenta, flour, silica, tap water	0.072	5.9	70	13	4.0 * 10 ⁵	1.0 * 10 ⁸	2.85
polenta, flour, silica, deionised water	0.201	51	305	23	6.7 * 10 ⁵	7.5 * 10 ⁷	2.96
polenta, oat bran	0.905	57	405	13	2.2 * 10 ⁵	5.0 * 10 ⁸	2.95
wheat flour, oat bran, sunflower press cake	0.652	40	324	11	4.0 * 10 ⁵	2.4 * 10 ⁸	2.98
compost leachate, wheat flour, oat bran	0.149	5.2	95	4.6	1.9 * 10 ⁶	3.1 * 10 ⁸	2.87
citric acid	0.130	97	94	19	2.0 * 10 ⁵	6.1 * 10 ⁷	2.73
citric acid, 96 h extraction	0.050	3.4	95	11	2.1 * 10 ⁶	2.8 * 10 ⁷	3.08
green leaf compost, oat bran	0.103	26	82	1.6	2.2 * 10 ⁵	7.3 * 10 ⁷	3.09
green leaf compost, oat bran, 96 h extraction	0.060	3.6	82	1.9	7.1 * 10 ⁵	8.8 * 10 ⁷	3.39
compost leachate, oat bran	0.503	88	288	4.2	4.6 * 10 ⁴	2.7 * 10 ⁶	3.36
green leaf compost, sunflower press cake	0.116	6.2	97	5.4	8.9 * 10 ⁵	2.5 * 10 ⁸	3.10

Neither support of plant growth nor microbiological parameters did change significantly during a storage time up to 72 hours at 10°C. At higher temperatures the tea was not stable longer than 24 hours which has to be considered for routine production and application, especially during hot summer time.

Micro-organisms detected by molecular biological methods in the compost could not be found again in soil after tea application. Nevertheless some slight changes in the soil composition were detected, proving that the observed small quality improvement in vegetables was related to the tea application. Significant differences in crop yield (harvest weight) were not observed.

Conclusions

Vermicompost-tea was found to be beneficial for plant growth and biomass production in laboratory experiments, correlating with microbiological parameters. All parameters were influenced by brewing and storage conditions in multiple ways. Nevertheless, compost tea quality was reproducible under certain conditions. Field experiments showed a more often beneficial effect of vermicompost-tea to crop quality but never to harvest quantity. If compost tea was applied to the field in the recommended amounts it is obvious that it does not act as fertiliser, more likely as a form of plant support.

It is strongly advised to follow up by investigating microbial population dynamics on plant surfaces due to tea application monitoring plant health and infection probability because of displacement effects.

Acknowledgments

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Session 4.2:

**Input of pollutants to soil due to application of
organic waste products /**

Implication for soil organisms and the food chain

Organic Pollutants in Secondary Fertilizers

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Key words: organic pollutants, secondary fertilizers, composts, digestates accumulation in soil, plant-uptake

Introduction

Composts, digestates, animal wastes like manure or sewage sludge are low-price fertilizers to improve agricultural soils. Their use is important in the context of closed substance cycle management for humus and nutrients. However, these fertilizers may contain pollutants which accumulate in agricultural soils, and thus, the benefits and threats for environment and plant protection are under discussion.

Materials and methods

In a coordinated project sponsored by the German UBA first data on the occurrence and concentrations of contaminants in secondary raw material fertilizers such as composts and digestates was compiled for priority organic pollutants. Data acquisition was done by both literature search and questionnaires sent to experts. In addition, identified data gaps for the substance concentrations in manure, composts, and digestates were closed by chemical analyses.

To investigate a possible accumulation of the organic pollutants in soil after application of secondary fertilizers, a comprehensive field survey was performed. Selection of sampling sites had to follow several criteria:

- Sites had to be located in different German states
- Consideration of different soil types
- History of fertilization regimes had to be documented
- Reference sites (no fertilization with sewage sludge) had to be available.

Soil samples from both the treated fields and reference sites were taken according to a well elaborated scheme. Samples were extracted and analyzed for organic priority substances. Additionally, metal concentrations were determined though the focus was on organic pollutants.

The evaluation of the analytical results was done by comparing pollutant concentrations and existing or proposed trigger values.

Results

The concentrations of the various organic pollutants in fertilizers differ significantly depending on their stability and ubiquitous occurrence. Table 1 presents the results.

Tab. 1: Pollutant concentrations [mg/kg dm] in different fertilizers

Pollutant	mineral fertilizer	liquid manure	Compost	sewage sludge	digestate
PCBs	0.001	0.004	0.02	0.05	0.01
PAHs (EPA)	0.26	0.20	3.01	5.5	1.43
NP+NPEO	0.03	0.17	0.03	17.0	4.77
LAS	138	164	42	1390	877
musk compounds: Galaxolid ® Tonalid ®	n.a.	n.a.	n.a.	12.8 4.0	n.a.
DEHP	0.86	1.79	30.1	27.0	29.7
DBP	0.05	0.07	0.20	0.25	0.81
organotin compounds	< det.limit	0.21	0.13	0.70	0.43

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As can be seen from table 1 ubiquitous substances such as PCBs and – partly – PAHs occur in low concentrations in the different types of fertilizers. Other organic compounds are present in fertilizers in fairly high concentrations. In particular, LAS, NP+NPEO, musk compounds, and phthalates were detected.

When applying these fertilizers to agricultural soils the non-persistent compounds are subjected to degradation whereas persistent pollutants can be detected in soils even many months after application. The following table 2 compares soil concentrations of sites which were fertilized with sewage sludge and reference sites.

Tab. 2: Comparison of soil concentrations of sewage sludge applied fields and reference sites

Pollutant	for most of the investigated sites concentration in soil of sewage sludge applied fields > reference sites	for most of the investigated sites concentration in soil of sewage sludge applied fields ≈ reference sites
B(a)P and Σ PAHs (EPA)		X
mono- and dibutyltin cation	X	
mono-octyltin cation		X
dioctyltin cation		X
LAS		X
phthalates		X
musk compounds	X	

Discussion and Conclusions

The results clearly show that non-persistent substances such as LAS, nonylphenols and nonylphenoethoxylates, and phthalates are degraded easily in soil after application. However, accumulation can be demonstrated for persistent pollutants like musk or organotin compounds. These substances could be used as “fingerprint” chemicals indicating a previous application of sewage sludge.

In order to identify the most environmentally relevant contaminants the environmental persistence of the contaminants as well as their potential to accumulate in soils has to be taken into account. Significant amounts of these substances must be applied in order to be detected.

In addition to their presence and stability in soil, the substances toxicity to soil organisms, uptake by plants, and transport to ground and surface water has to be considered for a comprehensive environmental evaluation.

In order to reliably and reproducibly assess the consequences of fertilizer application containing organic pollutants a commonly accepted assessment scheme should be developed.

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Effects of mid-term application of composts on agricultural soils in field trials of practical importance: Possible risks

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Key words: compost, agriculture, pollutants, inorganic, organic

Abstract

Composts from different plants, mainly processed biowaste (fruits, vegetables, leftovers) and all of certified quality, were applied in mid-term (9-12 y) field trials on five sites in SW Germany, to detect the beneficial effects on soil fertility and to estimate possible risks linked with their use. Four sites belonged to private farms. Regarding the German biowaste directive, the greatest risk resulted from the contamination with Cu and Zn. Both elements tapped the given limit for composts partially to a great degree. The content of other heavy metals (Cd, Hg, Ni, Pb) and organic pollutants (e.g. PCB and PCDD/F) were low so that an increase in the soils could not be detected until the end of the test period (2006). The mobile fraction of some heavy metals (Cd, Ni, Zn) even decreased, compared with the plots where compost has not been applied. The content of impurities (glass, metals, plastics), and stones fell well below the limits given by the biowaste directive, also pathogenic microbes (*Salmonella*), seeds and regenerating parts of weeds.

Introduction

In Germany at present about 10 Mio t of biowastes, mainly plant material and organic waste from households, are collected separately and converted to about 5 Mio t compost in about 800 plants (GK 2003). Dependent on its quality, the compost is used as organic fertilizer or soil improver in horticulture, agriculture, landscaping and for recultivation of soils.

The application of compost in these fields is regulated officially by the Bioabfallverordnung (federal biowaste directive; BMU 1998). To improve the acceptance of compost by consumers, the Bundesgütegemeinschaft Kompost, BGK, has installed a quality assurance system with quality assessments and controlling procedure (RAL 2007). In a joint research project, funded by the German Environmental Foundation and a follow-up project by the BGK and the LTZ Augustenberg, mid-term field trials with compost application were performed and accompanied by an intensive measuring programme with the aim to analyse/evaluate the beneficial impact of composts on soils and the risks on the environment linked with their use, respectively.

The following report deals with the estimation of risks, whereas in an accompanying paper (Bolduan et al. 2008) the effects on soil properties are reviewed.

Materials and methods

Beginning with the years 1995 and 1998 field trials were performed on 5 different typical tillage sites in SW Germany, 3 over 9 and 2 over 12 years, with periodic compost application and with uniform crop rotation (maize, wheat, barley). Four sites belonged to private farms, one was a trial field of the LTZ. The experimental design was a randomised bi-factorial combination of compost variants (0, 5, 10 and 20 t ha⁻¹ y⁻¹ DM) with supplementary nitrogen fertilization (0, 50 % and 100 % of the N amount according to the official fertilizer recommendation in Baden-Württemberg). All applied composts were of assured quality and have been analysed on their important physical, chemical and biological properties.

In 2002, the upper layers, at least, of the soils at all five sites were analysed on (among others): total content (extract with *aqua regia*) of heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) and mobile fraction (ammonium nitrate extract) of Cd, Cr, Cu, Ni, Pb, Zn, content of PCBs and PCDD/F.

Harvested plants were also analysed on relevant parameters.

Until the end of the field trials in 2005, the analyses of composts and of the soils of 3 sites were enlarged by some parameters. For information on the total analyses programme and details of the methods used see GK (2003) and LTZ (2008).

Results

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Important results of the research programme are the following:

- The contents of the undesired heavy metals Pb, Cd, Cr, Ni, Hg in composts with assured quality in general and the composts used in this study fall well below the limit values given by the federal biowaste directive; the contents reached only 30 % (in the mean) and 50 % (90 % percentile) of the limit.
- Higher exhausting rates of the limit values show only Cu and Zn (mean 50 %, unfavourable conditions 80 %). Even such rates seem to be tolerable if the contents of Cu and Zn in the soils at the site of compost application fall well below the background values.
- An increase of the contents of heavy metals in the used soils could not be detected analytically. There was only a slight, statistically not significant tendency of it in the case of Cu and Zn in the topsoil at high application rate (10 t ha⁻¹ y⁻¹ DM). Leaching of heavy metals into deeper soil layers can be excluded.
- The mobile fractions of heavy metals remained constant or (Cd, Ni, Zn) were reduced by compost application (results of the year 2002).
- The content of heavy metals in the harvested plant materials remained at the same level during the total research period.
- The mineralisable part of nitrogen in the soil organic matter increases with time of compost application, until 15 kg/ha N, seldom 25 kg/ha N. Nitrogen fertilizing by the farmer should be reduced accordingly, to avoid leaching of nitrates into the groundwater.
- Periodic analyses of composts on PCP and PCDD/F have shown very low contents. The originally given contents around the background values of non contaminated soils remained at the same level (PCB < 2 µg/kg, PCDD/F 1-2 ng/kg I-TEQ) during the research period.
- The same conclusion can be drawn from the determination of other organic pollutants, like organochloric pesticides, PAH, phthalates, chlorophenols,
- Hygienic risks from the application of orderly produced composts seem to be not given. In our own compost samples *Salmonella* and coliformic bacteria could not be detected in infectious amounts. The same is with phytopathogenic organisms. Seeds and regenerating parts of weeds were present only in practically negligible amounts. They did not influence the weed coverage at the trial sites.

Conclusions

Our conclusion is that risks, linked with the application of composts in agriculture, are not given or, as in the case of heavy metal loads and the mineralization of nitrogen from organic matter after some years of compost application, can be controlled by soil analyses.

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Input of organic pollutants in soil through compost application: possible transfer to plant

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Key words: Compost, soil, plants, organic pollutant, PAH, PCB, LAS, phthalates, nonylphenol.

Abstract

Organic Pollutants (OPs) have been studied in a long term field experiment with application of composts and farmyard manure. Their concentrations were measured in organic amendments, soils and crops. Results show that there is no detectable impact of organic amendment application on soil and crop qualities.

Introduction

Numerous studies have shown the presence of OPs in composts. The impact of compost application on soil and crop contents in OPs has been studied in a long term field experiment "Qualiagro". This experiment has been initiated in 1998 to study the effects of urban compost application on soil and plant qualities. Three composts (MSW, municipal solid waste compost; GWS, sludge co-composted with greenwastes; BIO, biowaste compost) are compared to a farmyard manure (FYM) and to a control non amended treatment (CTR). Composts and manure are applied every two years at doses equivalent to 4 t of C/ha, corresponding to approximately twice the usual rate of application. These doses were chosen to evidence the amendment efficiency at increasing soil organic matter content (Houot *et al.*, 2002).

Materials and methods

OPs (PAHs, polycyclic aromatic hydrocarbons; PCBs, polychlorobiphenyls; PCDD/F, polychlorodioxins and furans; DEHP, Di(2-ethylhexyl)phthalate, DBP, Di-n-butylphthalate, DIBP, Diisobutylphthalate, and other phthalates; NP, nonylphenol; LAS, linear alkylbenzenesulfonates) have been analyzed in the organic amendments, the soils and the harvested grains (wheat and maize). In addition, PAHs have been also analyzed in rain water over one year.

Results and discussion

Concentrations of OPs in the amendments (Table 1) and fluxes to soils: The largest concentrations were observed in GWS and MSW for all OPs, except for PAHs for which BIO has the highest concentration. Phthalates and LAS concentrations in GWS and MSW may be related to the nature of composted wastes: sewage sludges are known for containing both compound families and phthalates could come from plastic present in MSW before composting. Among phthalates, DEHP was the most abundant. NP was only detected one year in each amendment, at concentrations close to 100 µg/kg Dry Weight (DW) except in GWS (3 000 µg/kg DW). Finally, PCDD/Fs have never been detected in organic amendments. All OPs concentrations in composts and manure were consistent with previous published results (Brändli *et al.*, 2005) and were well below the EU Directive Project thresholds for sludge spreading on agricultural soils – draft 2003.

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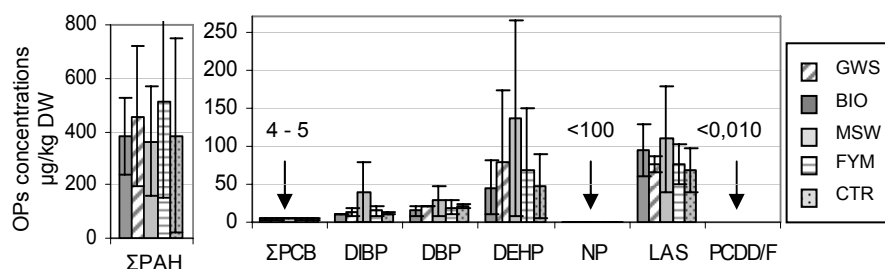
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Table 1. Concentrations of OPs in organic amendments ($\mu\text{g}/\text{kg DW}$) (years 2002, 2004 and 2006)

	Grading of the amendment by increasing concentrations	Medians concentrations ($\mu\text{g}/\text{kg DW}$)	EU Directive Project ($\mu\text{g}/\text{kg DW}$)
$\Sigma 16\text{PAH}$	FYM<MSW<GWS<BIO	753 - 3 059	6000
$\Sigma 7\text{PCB}$	FYM<BIO<MSW<GWS	10 - 101	800
LAS	FYM<BIO<GWS<MSW	81 - 7 983	5 000 000
DEHP	BIO<FYM<GWS<MSW	282 - 112 786	-
DiBP	BIO<GWS<FYM<MSW	112 - 1871	-
DBP	BIO<GWS<FYM<MSW	66 - 1386	-

Mean fluxes of LAS varied between 4 and 60 g/ha/2 years for all the organic amendments, except GWS for which fluxes reached 730 g/ha/2 years. Mean fluxes of DEHP were about 7 to 10 g/ha/2 years for BIO and FYM, but they reached 193 and 4 648 g/ha/2 years for GWS and MSW. Mean fluxes of ΣPAH varied between 10 to 70 g/ha/2 years, those of NEP between 1 to 20 g/ha/2 years and those of ΣPCB between 0.2 to 2 g/ha/2 years. PAHs fluxes through organic amendment applications were much larger than deposition measured in rain and also than the total atmospheric deposition reported in previous published studies. Depositions by rain represent a flux of PAH lower than 0.12 g/ha/year. In contrary, PCBs fluxes were comparable to atmospheric depositions reported in literature (Teil *et al.*, 2004).

Concentrations of OPs in the soils: In spite of these significant fluxes, no difference among the organic treatments neither between treatments and control was observed in soils (fig. 1). In 2006, after four organic amendment applications, PAHs were the most abundant OP found in soil, detected in all the treatments between 182 and 1 045 $\mu\text{g}/\text{kg DW}$. LAS and DEHP were also frequently detected but at lower levels <50 to 250 $\mu\text{g}/\text{kg DW}$. Other phthalates (DBP and DIBP) have been detected at around 5 $\mu\text{g}/\text{kg DW}$. PCBs were detected in all the plots between 3 to 7 $\mu\text{g}/\text{kg DW}$. Finally, NP and PCDD/F have never been detected. These results corresponded to reported concentrations in cultivated soils [4]. No accumulation of the OPs was observed in soil, it could be related to their different persistence and their abundance in organic amendments: The most persistent compounds (PCDD/F, PAH, PCB) were present at low concentration in amendments and the most abundant were the most biodegradable (phthalates, LAS).

**Fig. 1. Concentrations of OPs in soils ($\mu\text{g}/\text{kg DW}$), in 2006**

(4 organic amendments applications done, 4 plots per treatment)

Concentrations of OPs in the grains: No differences in the detected OPs concentrations were observed between the treatments (example of maize in Fig. 2). Moreover, concentrations in grains were higher than in soils and the OPs profiles in grains and soils were not correlated. In addition, concentrations were generally larger in wheat (harvests 2004 and 2006) than in maize (harvest 2005). Average concentration of LAS in grains (wheat and maize) was 690 $\mu\text{g}/\text{kg DW}$, but with variation between years. Average concentrations of phthalates in grains were 840, 181 and 100 $\mu\text{g}/\text{kg DW}$ for DIBP, DEHP and DBP, respectively. PAHs were not detected in the grains except naphthalene at very low concentrations (1.3 $\mu\text{g}/\text{kg DW}$). NP was detected one year in wheat in all the treatments with concentrations close to the quantification limit (100 $\mu\text{g}/\text{kg DW}$). No PCBs or PCDD/Fs were detected in the grains (respectively <1 and <0,01 $\mu\text{g}/\text{kg DW}$). The measured concentrations in crops corresponded to the few published data (Gibson *et al.*, 2005).

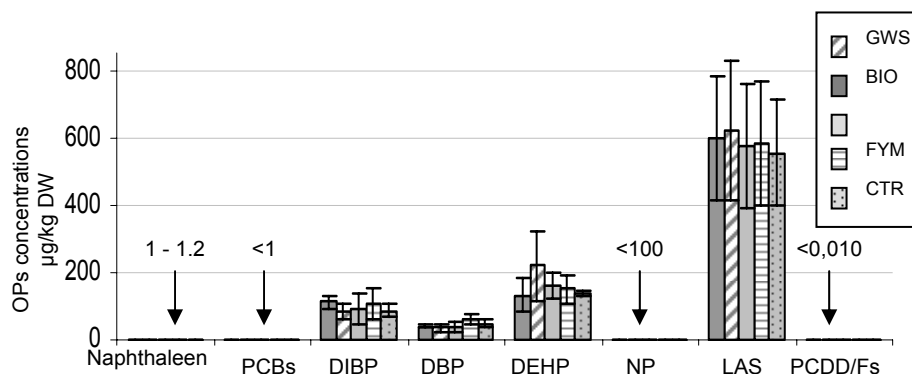


Fig. 2. Concentrations of OPs in maize grains ($\mu\text{g}/\text{kg DW}$), in 2005.

(4 organic amendments applications done, 4 plots per treatment)

Conclusions

In this experiment, the application of composts or manure generated fluxes of OPs which were significant compared to OPs initial stocks in soil and were probably also larger than atmospheric depositions. Nevertheless, no detectable accumulation of OPs in soil and no detectable impact on crop were observed. Other sources of contamination can be suspected to explain the presence of some OPs in plants: direct atmospheric depositions on plants or deposition of other agricultural products (phytosanitary products). Ongoing measurements will bring some additional information on the other source of OPs in cultivated soils.

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The safety of compost products

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Key words: Compost, maturity, quality, ecotoxicity, phytotoxicity

Abstract

This presentation provides a summary of our composting research activities during recent years at VTT Technical Research Centre of Finland.

Compost maturity assessment is an important quality criterion of compost. Our approach in this research originates from work carried out on developing standards in the CEN committee for the compostability of biodegradable polymers and packaging materials. The standards included criteria for biodegradability and the disintegration of packaging materials during composting. They also states that no harmful substances are to be released or formed during composting. Neither should the compostable biodegradable products affect the maturity of the compost.

In this presentation we demonstrate a test scheme that was developed to help testing laboratories and composting plants to assess compost maturity and ecotoxicity.

Introduction

Several types of organic pollutants are present in household waste composts, especially in sewage sludge, and these may end up in the final compost product. Increased recycling of organic wastes has raised concern about the end product quality of the compost products. In the present study we demonstrate a guideline for studying compost quality on the basis of stability and eco-/phytotoxicity testing. We also demonstrate the need for further studies on the effects of persistent organic pollutants (POPs) on soil health.

The role of POPs and their degradation in agricultural soils, and their bioaccumulation and migration in crops and subsequent effects on soil microbial communities, are still not sufficiently well understood. The toxicity caused by these chemicals, as well as the role of biological treatment technologies on end product quality, need further study. The degradation of POPs during composting, and later on in the soil, still need to be investigated.

Materials and methods

Composting experiments were performed in controlled conditions either in 200 l or 5 l bins with continuous aeration and online temperature and carbon dioxide measurement (Venelampi et al., Tuominen et al., 2002; Rajamäki et al., 2005).

The methods used to estimate stability were based on carbon dioxide evolution, and the nitrate/ammonium ratio (Itävaara et al., 2002). The phyto- and ecotoxicity of organic pollutants have been studied in plant growth assays modified from OECD 208, as well as by a kinetic luminescent bacterial assay, *Vibrio fischeri*, that is based on the decrease in bioluminescence. Microbial communities were analyzed by 16S rRNA and PCR-DGGE analysis and the sequences identified using databanks (Kapanen et al., 2007).

Results and Discussion

Packaging materials and their additives used as coating and filler substances may release toxic compounds during biodegradation in composting. Therefore tests are needed for assessing the safety of the final compost product. However, most of the soil ecotoxicity tests are not suitable for compost applications due to the high salt and ammonium concentrations. In addition, the presence of volatile fatty acids and excessive amounts of nutrients may also have an effect.

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Immature composts were found to be toxic in ecotoxicity assays to the test organism bacteria *Vibrio fischeri*. In order to be able to distinguish between the toxicity due to POPs and the toxicity due to naturally occurring degradation products, we have studied immaturity, maturity and ecotoxicity under controlled conditions.

Finally, we have proposed a test scheme for estimating the maturity and ecotoxicity of composts.

Acknowledgments

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Waste imprint on soil quality in a long-term urban fertilizer field trial

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Key words: field trial, soil quality, organic waste, long term effects, microbial functionality

Abstract

We here present the first results of a Danish long-term field trial using urban fertilizers like composted household waste and sewage sludge. The facility was established in 2002 to investigate possibilities of recycling of urban organic waste in agriculture and to discern the effects on soil quality. We now see differences between treatments but have not observed any detrimental effects on soil function.

Introduction

Waste management systems of today have developed without primary concern for recycling. Sewage sludge and compost are organic resources but they can contain unwanted contaminants. Sewage sludge from treatment plants contain heavy metals and xenobiotics and are not considered an attractive manure source in agriculture and unacceptable in organic farming. Interdisciplinary studies on integrated ecological waste management systems have lead to development of the CRUCIAL² project (Magid *et al.*). This includes a unique long-term trial on agricultural soil that uses different urban and reference fertilizers at two different levels, among which are human urine, sewage sludge and degassed and composted household waste. A further introduction to the site, its applications and future use will be given at the CODIS 2008 conference.

According to calculations, the eco-toxicological limits in plots with high input of sewage sludge and composted household waste can be approached over 3-10 years (depending on quality of the source). Data (2005) shows an increase in the concentration of selected metals in the treated plots compared to the control plots. This indicates that effects of organic resource application in the field trial are beginning to show.

Materials and methods

The field trial is situated at the experimental farm of the Faculty of Life Sciences, University of Copenhagen, placed in Tåstrup 20 km east of Copenhagen. It includes 11 treatments on 33 plots of 891 m² each, in a random block structure. The treatments are: human urine, sewage sludge (normal and accelerated level), degassed and composted household waste (normal and accelerated level), deep litter, cattle slurry, cattle manure (accelerated level), NPK fertilizer, green manure and control (unfertilized). It was establishment in 2002 using annual fertilizer application rates adjusted to Danish legislation concerning total-N application. The fertilizers have been applied annually and the fields have been grown with a sequence of crops.

At present we are conducting a basic characterization of the soils (sampled 2007) including determination of heavy metals, carbon and nitrogen content, respiration, soil microbial biomass, nitrogen mineralization, number of bacteria (CFU) and sole carbon source utilization as an indication of functional diversity of the microbial community.

Results

Some of the provisionary results are given in Table 1. These show that the basal respiration increase with input of biomass and that the treatment with high level composted household waste has the highest respiration and increase in both total C and N when comparing all treatments. The content of inorganic N is also highest in the high level treatments. The high level treatments of composted household waste and sewage sludge have the highest number of CFU while the unfertilized control and the human urine treatments have the lowest number. However, the growth pattern, as indicated by how fast the colonies appear on the plates, is the same for all treatments (data not shown). Sole source carbon utilization of the soils has been investigated by use of Biolog[®] EcoPlates and the results do not indicate lower functional capacity in the treatments with higher metal loading (data not shown).

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² Closing the Rural-Urban Nutrient Cycle – Investigation of Urban Fertilizer pre-treatments, Agronomic research on Urban Fertilizer turnover in soil and impact on Crop growth, and Initiation of a Monitoring Program on Soil Quality changes brought by using Urban Fertilizers in Long-term Field Trials

Tab. 1: Characteristics of selected CRUCIAL soils receiving different fertilizer treatments

	Total %C	Total %N	N mineralization ¹ (µg N/g soil/day)	Inorganic N ² (µg N/g soil)	Basal respiration ³ (mg CO ₂ -C/kg soil/day)	CFU (CFU/g soil)
Untreated control	1.423 (0.054)	0.150 (0.005)	0.433 (0.303)	7.090 (4.280)	7.47 (0.14)	7.4*10 ⁵ (1.2*10 ⁵)
Human urine	1.652 (0.190)	0.170 (0.016)	0.579 (0.103)	15.578 (3.875)	8.00 (0.24)	5.6*10 ⁵ (0.6*10 ⁵)
Cattle manure (high level treatment)	1.764 (0.087)	0.179 (0.011)	0.717 (0.077)	21.527 (3.314)	9.28 (0.21)	1.1*10 ⁶ (0.1*10 ⁶)
Sewage sludge (high level treatment)	1.631 (0.129)	0.175 (0.016)	0.693 (0.410)	27.499 (5.892)	9.01 (0.68)	1.3*10 ⁶ (0.5*10 ⁶)
Composted household waste (high level treatment)	2.253 (0.142)	0.238 (0.017)	0.551 (0.230)	35.723 (6.761)	10.41 (0.09)	1.4*10 ⁶ (0.6*10 ⁶)

Results are given as the mean result of three plots receiving the same treatment. Standard deviation is in parenthesis

¹ Day 19-34 of incubation experiment

² Day 19 of incubation experiment

³ Measured at the initiation of the incubation experiment, after three week pre-incubation of the soils

Discussion

At present, after running the experiment for 5 years, waste imprint on the soil is showing. However, no detrimental effects are observed on e.g. potential functional diversity of the microbial community. The differences that have been observed are most profound in the high level treatments which are heavily accelerated compared to the normal treatments.

Ongoing investigation include analysis of crops (yield, N-uptake, metal analysis of the grain). Identification of antibiotic resistant bacteria in the soil samples will also be performed in order to assess the potential of resistance gene transfer in the environment. Additionally, several other research groups are presently using the CRUCIAL site for investigation of aspects like potential mineralization of PAH's and content of hormones and hormone derivatives. This is in keeping with the defined aim of the CRUCIAL facility which is to contribute to the knowledge of cycling of matter and plant and soil quality. Cycling of matter is in this context broadly defined and includes e.g. nutrients, heavy metals and xenobiotics, in addition to changes in the microbial community and gene pool and how all these affect the environment and agricultural system in particular.

Conclusions

If organic waste resources are to be an attractive supplement or alternative to other products in agriculture, the combined effects after long-term application need to be established (Giller *et al.*). The present results from the CRUCIAL field trial shows waste imprint on the soils. However, even after substantial loading with composted household waste and sewage sludge we observed no detrimental effects on the function of the system. Further work is needed to determine the possible effects of these changes for the agricultural soil system.

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PCB uptake by carrots after sludge and compost application

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Key words: Organic pollutants, organic waste products, plant growth, chemical analysis, food chain

Abstract

*A study on behavior of PolyChloroBiphenyls (PCBs) in a sand/soil - plant system has been carried out with the reclamation of sludge from wastewater treatment plant for agriculture in mind. Carrot plants (*Daucus carota*) have been grown in plant containers amended with organic waste products under operational practice inside a temperature and humidity regulated plant house. Compost application increases carrots biomass production. PCBs uptake has been followed into the core, the peel and the leaves of the carrots. The results clearly show that the trace organics are lower than the limit of quantification in all cases.*

Introduction

Polychlorobiphenyls (PCBs) are the most important class of ubiquitous priority pollutants whose mutagenic/carcinogenic and endocrine disrupting effects on biota have been reported (Winneke and al., 2002), (Fischer and al., 1998), (Gan and Berthouex, 1994). Although gradually banned since the seventies and eighties due to their toxicity (Saison, 2001), they are still present in the environment owing to their high physical, chemical and biological stability and the continued presence of various sources. The most important problem with PCBs is their potential for transmission within the food chain. Accordingly, the objective of this study is to investigate potential PCBs transfer from organic waste products (sludge and composts) amended soil into a food-chain crop under operational practice. Carrots (*Daucus carota* L. var. Amsterdam A.B.K. Bejo) were chosen as the test crop because they have been reported to be the crop having the greatest potential for organic uptake due to their high lipid content (Wild and Jones, 1992).

Materials and methods

Carrot plants were grown on sand and on soil in plant containers (2L) inside a temperature regulated greenhouse. A total of 24 pots have been used for the sand experiment to study transfer: 6 control pots (carrots + sand + nutrient solution), 6 sludge pots (carrots + sand + sludge 30tDM/ha), 6 moderate compost pots (carrots + sand + sludge compost 25tFM/ha) and 6 extreme compost pots (carrots + sand + sludge compost 65tFM/ha).

Soil cultures closer to reality (18 pots) were carried out in order to evaluate the real impact on transfers of an agronomic use of organic waste products: 6 control pots (carrots + soil + nutrient solution), 6 moderate compost pots (carrots + soil + sludge compost 25tFM/ha) and 6 moderate compost pots (carrots + soil + organic amendment 25tFM/ha).

Seven PCB isomers (IUPAC codes: 28, 52, 101, 118, 138, 153 and 180) were determined. Carrots foliage, root peel, root cores, soil and organic amendments were analysed by gas chromatography with mass spectroscopy detection in single ion monitoring mode. The limit of quantification was 1 µg/kg FM for each PCB.

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Results and discussion

Statistical Newman-Keuls tests show that there were significant differences ($p < 0.05$) in growth between carrots on sand with compost and carrots on sand with sludge with the same quantity of organic matter in pots: compost increases biomass production.

A total of 150 samples have been analysed. PCBs concentrations in sludge were lower than the limit of quantification and those in sludge compost were lower than 13 $\mu\text{g}/\text{kg}$ FM (Tab. 1). PCBs concentrations in plants (leaves, core and peel) for treatments and controls pots were lower than the limit of quantification (1 $\mu\text{g}/\text{kg}$ FM). Thus, no transfer was observed.

Tab. 1: Compost, organic amendment and sludge characterisation (FM: Fresh Matter; DM: Dry Matter)

	Compost	Organic amendment	Sludge
pH	8.3 \pm 0.0	8.7 \pm 0.0	8.7 \pm 0.0
dry matter [% FM]	68.8 \pm 0.0	82.9 \pm 1.0	19,7 \pm 1.0
organic matter [g/kg DM]	538 \pm 26	463 \pm 4	772 \pm 10
PCB 28 [$\mu\text{g}/\text{kg}$ FM]	<1	<1	<1
PCB 52 [$\mu\text{g}/\text{kg}$ FM]	4.1 \pm 1.7	<1	<1
PCB 101 [$\mu\text{g}/\text{kg}$ FM]	6.4 \pm 2.5	<1	<1
PCB 118 [$\mu\text{g}/\text{kg}$ FM]	5,6 \pm 5,9	<1	<1
PCB 138 [$\mu\text{g}/\text{kg}$ FM]	8,5 \pm 3,6	<1	<1
PCB 153 [$\mu\text{g}/\text{kg}$ FM]	10,0 \pm 2,7	<1	<1
PCB 180 [$\mu\text{g}/\text{kg}$ FM]	1,7 \pm 2,0	<1	<1

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Session 5:
**Effects of composts and digestates on
ecosystems.**

Benefit of ecotoxicological tests for the characterization of composts

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Keywords: Ecotoxicological tests, contaminants, availability, assessment

Abstract

Depending on the source material, compost contains organic and/or inorganic contaminants. To obtain information on the available content of the contaminants it would be desirable to have ecotoxicological tests as being successfully applied for soils and waste material. For these substrates, standardized biological tests and assessment criteria are available; their application as a supplement to chemical tests has partially resulted in modified assessments of soils. Due to their considerably higher nutrient and organic matter content and potential differences in salinity, pH and structure, composts significantly differ from soils and wastes. The toxicity of compost can be the result of both natural and anthropogenic substances. It is, however, difficult to obtain information describing only effects caused by anthropogenic substances. Moreover, it is essential to differentiate between assessments of the pure material and those referring to the intended use. Compost is frequently added to improve soil quality and may be diluted before application. As a consequence, the contaminants present in the compost will be diluted as well and can fall below the threshold value for toxicity. In this case, undesired substances will not be detected.

Introduction

Depending on the source material contaminants occurring in composts may be of organic and/or inorganic nature. The quality of composts is controlled by substance specific chemical analysis usually considering parent compounds, but not metabolites. Moreover, analysis concentrates on the total concentration of the chemical substances without differentiating with respect to their availability.

Ecotoxicological tests have been successfully applied for many years to characterize contaminated and remediated soils. The tests are suitable to detect all available toxic substances. They include parent compounds as well as metabolites. Furthermore, the tests give information about the real hazard of the material, as only the available substance portion is determined. In the year 2000, a round robin test with 64 participants, mainly from Germany, was performed for soils. Four contaminated soils differing in their contamination were investigated using aquatic and terrestrial tests. On the basis of the results of this test and former joint projects, a recommendation of a test battery for soil assessments was elaborated. Meanwhile, the elaborated test methods are available as ISO-guidelines.

Due to the successful application of the tests in soil assessments, their application was extended to further materials, such as artificial soils prepared from organic and inorganic materials or wastes. In 2006/2007 an international round robin test was performed to find out whether the methods were suitable for the characterization of wastes. The investigations included incineration ash, waste wood and a gasworks soil.

The experience gained from the application of the tests is further reflected in several ISO-guidance documents. Examples are the guidance documents "Choice and evaluation of bioassays for ecotoxicological characterization of soils and soil materials" (ISO/DIS 17616) or "Selection and application of methods for the assessment of bioavailability in soil and soil materials" (ISO/DIS 17402). A guidance document on the application of ecotoxicity tests for waste material is in preparation; among other things it includes the assessment of sludge designated for agricultural use.

So far, not much experience is available for the application of ecotoxicological tests on compost. An overview on ecotoxicity tests for compost applications was published by Kapanen & Itävaara (2001). In the following paragraphs test systems commonly applied for soil and waste assessment are presented, and the possibilities and limitations of these systems to characterize compost materials are described.

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Materials and methods

The test systems usually applied to assess soils and wastes are based on standardized test systems with aquatic and terrestrial organisms which had originally been elaborated for chemicals testing.

To assess the retention function of the material, tests with aquatic organisms performed in aqueous soil or waste extracts are used. For these tests, an eluate is prepared which represents the leachable portion of the contamination (ISO 21268). Suitable organisms for tests with eluates are luminescent bacteria, daphnids and algae. Considered endpoints are luminescence (*Vibrio fischeri*; EN ISO 11348), immobilization (daphnids, ISO 6341) and growth (algae, ISO 8692). Further to ecotoxicological effects, genotoxicity can be determined. A suitable test system is the umu-test with *Salmonella choleraesuis* (ISO 13829). Detection of an effect indicates the presence of toxic substances which can leach into the groundwater or adjacent ecosystems.

To assess the habitat function of soils in the scope of soil and waste assessments, terrestrial test systems are used which provide information on whether organisms can survive and reproduce in the investigated material. For a comprehensive assessment a test battery comprising several test organisms has to be applied, since it yields information on organisms of different and supplementary sensitivities. So far, suitable methods exist for a number of organisms, e.g. microorganisms, plants, earthworms and collembolans. They comprise the endpoints respiration activity (ISO 17155) and nitrification (ISO 15685), activity of microorganisms, reproduction capacity of earthworms (ISO 11268-2) and collembola (ISO 11267) as well as germination and growth of plants (ISO 11269-2).

For the above aquatic and terrestrial tests criteria were elaborated to classify the tested substrates with respect to their toxicity.

Results and discussion

Not much experience is available for ecotoxicological tests with compost. Therefore, results obtained for soil and waste assessments on the basis of biological tests are presented in addition to results obtained for compost. In so doing, suitability and limitations of the presented tests concerning the assessment of different substrates are demonstrated.

Experiences with ecotoxicological tests in the scope of the classification of soils

Ecotoxicological tests are successfully applied to soils. However, arising costs are only justified if an added value is obtained and the information obtained in the soil assessment is suitable to support the decision making process concerning a reuse of the soil material.

To prove the added value for a test soil, soil material which had been excavated during a construction process was classified with the common procedure. Further to this, the soil was assessed with biological tests using a test battery that included aquatic and terrestrial tests (Römbke et al, 2006). Selected results are presented in Table 1.

Various combinations of results were obtained. The necessity for deposition of the soils 1 und 2, which had been demonstrated by chemical analyses, was confirmed by the results of the biological tests. Considering the genotoxic effects, however, soil 2 would be classified more toxic than soil 1. According to the biological tests, deposition of soil 3 would not be necessary, since a potential for leaching of the contaminants was not detected. Therefore, further use of soil 3 as a sub-soil seems to be justified. For soil 4, the biological analysis of the available contaminants does not justify combustion. Based on the results, the decision on a reuse could be reconsidered for two soils when taking into account the available content of contaminants as identified by biological analyses. Further to the presented results, there are other investigations where ecotoxicological tests indicate affected soil functions which had not been observed by previously performed chemical analyses.

Table 1: Assessment of soil material based on ecotoxicological tests

Test	Soil 1 (HSH-OB1-0504)	Soil 2 (HSH-OB3-0504)	Soil 3 (HSH-OB4-0504)	Soil 4 GBK-3C-0503
"Reuse" according to chemical analyses	Landfill Category III according to the contamination level	Landfill Category II according to the contamination level (concentration lower compared to landfill cat. III)	Landfill Category II according to the contamination level	Combustion
Habitat (terrestrial ecotoxicity tests)	Highly limited (toxic effects in three of five test systems)	Highly limited (toxic effects in three of five test systems)	Limited (toxic effects in two of five test systems)	No toxicity
Retention function (ecotoxicological tests in soil eluate)	Highly limited (toxic effects in one of two test systems)	Highly limited (toxic effects in one of two test systems)	No toxic effects detected	No toxicity
Retention function (genotoxicological tests in soil eluate)	No genotoxic effects detected	Small inhibition	No genotoxic effects detected	Genotoxic effect
Recommendation: biology	High potential of available contaminants	High potential of available contaminants	Low potential of available contaminants → Use as subsoil possible	Combustion not necessary

Experiences with ecotoxicological tests applied for wastes

The above-mentioned round robin test initiated by the EU: "European Ring Test – Ecotoxicological Characterization of Waste", demonstrated the applicability of ecotoxicological tests for wastes. Besides a gaswork soil (SOI), incineration ash (INC) and waste wood (WOO) were tested. The toxicity of the substrates differed considerably. WOO was most toxic, while SOI caused effects only occasionally. The number of invalid data sets was low. Following the approach published by a Canadian governmental institution, Environment Canada, all results are acceptable which fall within a range of two standard deviations from the long-term geometric mean (EC, 1999).

Figure 1 exemplarily represents the results obtained from testing waste wood by using tests with algae (Römbke and Moser, in preparation): The results of two tests (both with *Pseudokirchneriella subcapitata*) were outside the warning limits. Obvious is the different sensitivity of the two species, both listed in the guideline for alternate use.

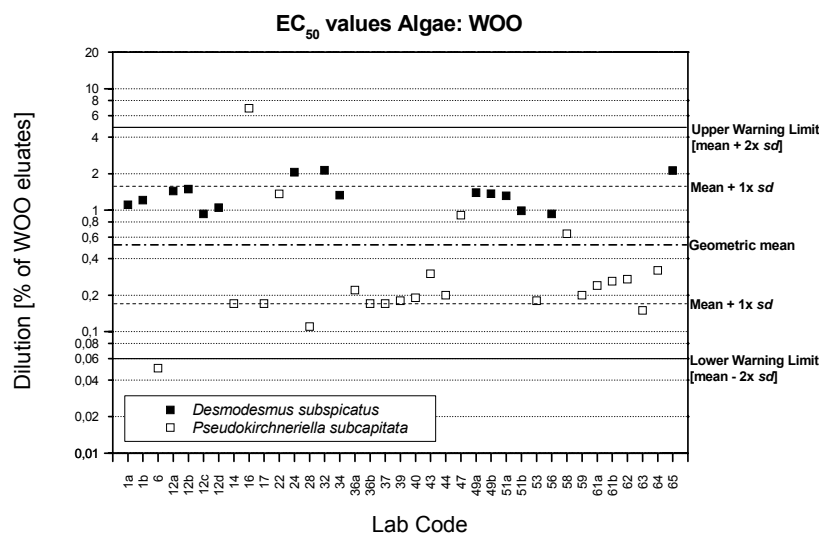


Figure 1: Growth test with algae: eluate of waste wood

No limitations were observed for the terrestrial tests (plant test, mortality test with earthworms). The results obtained for incineration ash using the test species *Brassica napus* are presented in Figure 2. Out of 18 valid tests, the result of only one test was outside the warning limits.

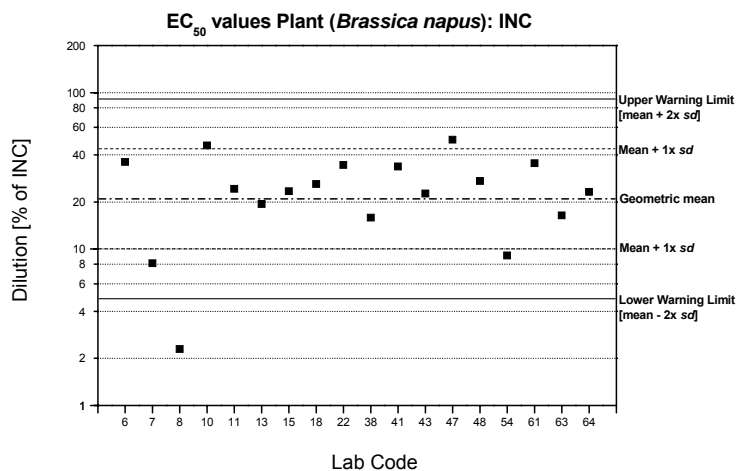


Figure 2: Growth test with plants: incineration ash

Summarizing the available experiences it seems that – despite the very heterogeneous test substrates – the results of the round robin test were well within the range of other ecotoxicological round robin tests that had been performed with individual chemicals spiked into homogenous standard substrates. No limitations were observed for the investigated wastes.

Experiences with ecotoxicological tests applied for compost

Composts in many respects differ from the previously described substrates. They have a high nutrient and organic carbon content. Structure, pH, salinity and ammonium content differ. In some cases also a lack of oxygen caused by a high microbial activity is observed. Compost passes through a process of maturing. Immature compost contains comparably high concentrations of natural substances (e.g. acids) that can cause toxicity. Immature compost also can inhibit plant growth through nitrogen immobilization in situations when a high C/N ratio causes competition for available nitrogen between roots and soil microorganisms (Kapanen & Itävaara, 2001).

Therefore, the question arises to which extent ecotoxicological tests are appropriate for composts. Table 2 presents some results obtained from aquatic ecotoxicological tests (**retention function**) with eluates prepared from input material for composts and eluates from composts. Three frequently applied ecotoxicological assays were used. Different input materials and different composting techniques were considered. All input materials and composts were derived from technical composting plants.

Table 2: Ecotoxicological tests with compost eluate (retention function)

Material	<i>Vibrio fischeri</i> : Luminescence inhibition		<i>Daphnia magna</i> : immobilization		<i>Desmodesmus subspicatus</i> : growth
	LID-value ¹	EC ₅₀ [mL/L] ²	LID-value	EC ₅₀ [mL/L]	Effect
Input					
GA – biowaste (collection area: rural)	> 16	161	4	228	Stimulation
LE – sewage sludge (collection area: urban)	> 16	150	16	> 250	Stimulation
FR – biowaste (collection area: rural + urban)	> 16	120	4	39	Stimulation
OL – biowaste (collection area: urban)	> 16	100	> 64	79	Simulation
Compost					
GA – aerobic treatment	16	334	4		Stimulation
GA – anaerobic treatment	8	570	4	> 250	Stimulation
LE – aerobic treatment	12	305	4	> 250	Stimulation
FR – aerobic treatment	> 16	60	8	> 250	Stimulation
OL – aerobic treatment	8	465	4	> 250	Stimulation

¹: LID-value: lowest ineffective dilution, i.e. dilution at which the effect is slightly below 20 % in the luminescence and algae test or maximum 10 % in the test with daphnids

²: EC₅₀: effect concentration, i.e. concentration at which 50 % of the test organisms are affected.

The results can be summarized as follows:

- The eluates showed a dark brown colour due to humic acids.
- The results obtained with the different test organisms (luminescent bacteria, daphnids, algae) differ.
- Biological effects were observed for input material and for composts.
- In most cases, the effect for the compost was less pronounced than that for the input material.
- Luminescent bacteria were inhibited by both input material and composts.
- In the tests with daphnids the eluates had to be diluted (eluate + water: 1 + 3) before test start to detect the organisms in the coloured solutions. In contrast to the eluates prepared from the input material, no effect was observed for the so-diluted compost eluates except for one compost (FR aerobic treatment).
- The eluates caused a stimulation of algal growth.

Besides ecotoxicological tests comprehensive chemical analyses were carried out. The analyses comprised heavy metals (Ni, Cu, Pb, Cd, Zn, Cr, As) and organic contaminants (PCB's 28, 52, 101, 138, 153, 180; α -, β -, γ -HCH, DDT and its metabolites DDE and DDE; 19 PAHs, the phthalates benzylbutylphthalate, diethylhexylphthalate, dibutylphthalate; hydrocarbons, BTEX: benzene, toluene, ethylbenzene, o-, m-, p-xylene, chlorinated benzene; content of phenols; and the preserving agents

thiabendazole, 2-phenylphenole and diphenyl). The determined concentrations were far below their toxicity levels for the organisms. Even when assuming an additive toxicity, effects are not to be expected. Therefore, we assume that other ingredients are responsible for the effects. Possible explanations for this are discussed in the following.

Luminescence test

In this test, the considered criterium is the intensity of luminescence. As compost eluates are of dark brown colour caused by humic substances, the colour of the eluates was considered by performing a colour correction. Therefore, colour as a reason for the inhibiting effect is excluded.

Besides an inhibition by contaminants, the luminescence is reduced by increased concentrations of easily degradable nutrients (e.g. ≥ 100 mg/L peptone, urea, yeast) and upon limited oxygen supply ($O_2 < 0.5$ mg/L). Oxygen supply can be limited as a result of chemical reactions, or by microbial activity. Composts contain many degradable carbon sources and high numbers of microorganisms. If the carbon sources are degraded by microorganisms during the incubation period, the oxygen can decrease below the threshold value of 0.5 mg/L, resulting in an inhibition of luminescence which is not an effect of contaminants.

Growth test with the alga *Desmodesmus subspicatus*

It is assumed that the growth test with algae is influenced by an excess of nutrients. In our tests, concentrations of nitrogen and phosphorous in the eluates exceeded the concentrations recommended for the growth medium. Although this was considered by supplementing the growth medium in the control vessels according to the concentrations measured in the eluates, a stimulation of growth was observed. Therefore, it has to be assumed that further nutrients, such as trace nutrients, have an influence on growth. As compost eluates are very complex mixtures, it is impossible to consider all nutrients that influence the stimulation of growth. Consequently, it cannot be excluded that inhibiting effects of contaminants are masked by such stimulating effects.

Immobilization test with daphnids

Short-term tests reflecting mortality are less sensitive than reproduction tests or tests based on physiological parameters, such as luminescence. In the test with daphnids, the endpoint "immobilization" is comparable to the endpoint "mortality" and, accordingly, of comparable sensitivity. Our results demonstrated that the test is relatively robust: In contrast to the test with algae, the results are not influenced by additional nutrients. Reduced exposure to light is tolerable, since a direct effect of reduced light on behaviour can be excluded and takes no influence on the assessment of immobilization. The only interference factor is the oxygen concentration. According to the guideline, oxygen concentrations < 2 mg/L have to be avoided. Although the oxygen concentrations fell below 1 mg/L in our tests, a correlation with immobilization was not observed. For example, immobilization of the daphnids was not observed in an eluate with an oxygen concentration of 0.7 mg/L at the end of the test. Therefore, the immobilization test with daphnids seems to have the lowest interference of natural substances and measuring parameters compared to the other tests with compost eluates using other standard organisms. As, however, the measuring endpoint "immobilization/mortality" is less sensitive than the endpoints determined in the other tests, the test with daphnids exhibits the lowest sensitivity.

The following paragraphs present some results and general remarks concerning the testing of the **habitat function**.

The earthworm species *Eisenia fetida* is a compost worm which is always present in composts. Its habitat is organic rich material. Some results obtained for this organism are presented in Table 3.

Table 3: Mortality test with the compost worm *E. fetida* (habitat function)

Material	Mortality [%]	Conductivity [mS/cm]
Artificial soil (control)	0	0,08
OL – input	50	1,46
OL – compost	100	2,04
FR – input	45	0,70
FR – compost	15	0,75

Although *E. fetida* is a compost worm, high mortality was observed in the investigated composts, whereas no mortality occurred in the control soil. The reason for mortality may be the salt content which is reflected by conductivity (mortality increases with increasing salt content). Further compost experiments with preceding reduction of salt concentrations by leaching resulted in 100 % survival of the worms. Consequently, the strong reaction of the earthworms may be due to the unfavourable habitat. Additionally it has to be taken into account that the worms were not adapted to high salt contents, as they had been cultured in artificial soil consisting of sand, kaolin and dung. In nature, compost worms may be adapted to the substrate.

The test parameters usually applied for microorganisms - the determination and assessment of microbial activity in the substrate - are not suitable for composts. As microbial activity is always high in composts and in the respective input material, the determination of microbial activity gives no further information.

It is also expected that an assessment of the compost based on plant tests cannot be performed by using compost as single growth substrate, since the conditions of growth do not seem to be appropriate for the agricultural plants recommended in the test guideline.

Collembolans live in air-filled pores. Therefore, a test with collembolans may be applicable, although it cannot be excluded that the high salt content in the pore water may affect the organisms. Concerning tests with *F. candida* it has also to be considered that this species feeds on microorganisms. Since compost is very rich in this food resource, this may be the reason for increasing offspring observed in compost in comparison to artificial soil (e.g. Cronau et al., 2002). Therefore, toxic effects caused by contaminants would be masked also in this test by an increased number of offspring resulting from a rich food resource.

The presented results show that an assessment of compost using ecotoxicological tests has to be more sophisticated than assessments of other substrates like soils and solid wastes. For compost testing the following topics have to be considered:

- Compost differs from the natural habitat of the test organisms in many parameters. Examples are pH, nutrients, salinity, composition and concentration of organic substance, C/N-ratio. Therefore, results obtained from ecotoxicity tests have to be interpreted carefully.
- Compost passes through a process of maturing. Results indicating toxicity in the tests can therefore be due to immature compost. Toxicity caused by natural compounds will disappear during the maturation process.
- The maturation of compost can be followed with ecotoxicological tests.
- Effects of anthropogenic contaminants can be masked by effects caused by natural compounds.
- Due to sorption processes, the available portion of anthropogenic compounds will be decreased and can only be detected at high concentrations exceeding the threshold values of toxicity.
- Test organisms cultivated as described in the guidelines may be less suitable for testing, unless they will be adapted to the substrate before the test. Additionally, other test organisms that can survive in pure compost and further endpoints can be selected. As a consequence, a long period of time will be needed until test organisms, culture conditions and test designs will have been elaborated and standardized to meet the requirements of a harmonized assessment. A harmonized assessment strategy, however, is a prerequisite for the elaboration of generally accepted results.

An alternative to testing the pure compost is to investigate the material with respect to the intended use as a soil ameliorant. Testing mixtures of soil and compost yields information on effects at environmentally relevant conditions. Information is achieved on whether the habitat function of soils will be improved by compost application. Small amounts of compost in soil can be investigated using the procedure generally applied for soil and waste assessments. However, the detection of unacceptable compost ingredients depends on the dilution factor implying that the possibility to detect undesired ingredients decreases with decreasing amounts of compost.

Conclusions

Ecotoxicological tests generally are a complement to chemical analyses: In addition to substance specific analysis carried out to determine total contents of contaminants they contribute information on the toxicity of available contaminations. The applicability of ecotoxicological tests based on standard test organisms has been demonstrated for soils and wastes. For the assessment of composts a more sophisticated approach is required, since many physicochemical properties of composts, such as pH, nutrients, salinity, C/N-ratio, and composition and concentration of organic substance, differ from the natural habitat of the test organisms as well as from soil and waste. Therefore, results from ecotoxicity tests with composts have to be interpreted carefully all the more so as stimulation and inhibition by natural and anthropogenic substances may mask each other.

An alternative to the testing of pure compost is to test soil/compost mixtures corresponding to real applications. If such mixtures are assessed it has to be considered that a dilution of the compost results in a dilution of the toxic substances as well. As a consequence, the contaminant concentrations can fall below the threshold value for toxicity, and undesired substances will not be detected. If these substances are persistent and compost application is performed several times, the contaminants will accumulate and cause effects at later points of time.

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Effects of composted organic waste on ecosystems – a specific angle: The potential contribution of biowaste to tackle Climate Change and references to the Soil Policy.

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Key words: LCA, Climate Change, C sequestration

Abstract

The contribution of the agricultural sector to emissions of climate change gases is becoming better understood. At the same time, the potential role of the sector as a means through which to tackle climate change, widely neglected in the past, is becoming more widely acknowledged. The absorption potential of agricultural soils could contribute significantly to the fulfilment of the reduction objective of the EU, which is -8% between 2008 and 2012 from a 1990 base. Many measures related to organic fertility of soils have been singled out by the WG agriculture of the European Climate Change Programme, among which

- “Mitigation potential of Nitrous Oxide emissions from agricultural soils” and
- “Sequestration potential of agricultural soils”

This might be properly tackled through a strategy aiming at proper reuse of composted organic waste. Actually, in addition to the measures listed above, many other possible side-effects of compost application may have some relevance, e.g. replacement of chemical fertilisers (implies avoidance of Greenhouse Gases and energy uptake related to their production) reduced use of pesticides (might imply avoiding emissions for their production), improved tilth and workability (might lead to less consumption of fuels) etc. Also, some LCAs seem to show some intrinsic limitations related to criteria for accountability of effects (as far as e.g. C sequestration is concerned) which impairs a true assessment of the potentially powerful contribution of proper management of Biowaste. The contribution singles out basic figures and (above all) strategic views for a preliminary assessment of the contribution of composting to tackle climate change issues, which, albeit affected by various uncertainties, cannot be neglected any more when it comes to environmental policy-making.

The potential contribution of compost and soils to tackle climate change

The contribution of the agricultural sector to climate change through emissions of greenhouse gases (GHGs) is becoming better understood. At the same time, the potential of the agricultural sector to contribute to reducing emissions of the same GHGs, widely neglected in the past, is now becoming better understood, both from a scientific and from a strategic (i.e. in policy-making) standpoint.

A poorly known fact is that it has been estimated that more than twice as much carbon is held in soils as in vegetation or in the atmosphere (Batjes, 1996). A starting point might be the following figures (taken from final reports of the WG Agriculture, European Climate Change Programme, 2001): in 1990, methane emissions from agriculture were 41% of all CH₄ emissions, while nitrous oxide emissions from the sector accounted for 51% of total N₂O emissions. Taking into account also emissions of carbon dioxide, GHG emissions from the agricultural sector amounted to 11% of all EU GHG emissions in 1990.

On the other hand, the potential of agricultural soils to act as a sink for carbon suggests that this function could contribute significantly to fulfilling the objective of the EU to reduce GHG emissions by 8% between 2008 and 2012 from a 1990 base. Considering the above, the 6th Conference Of the Parties (COP 6 bis) held in Bonn in July 2001 considered agricultural soils to be suitable as sinks for the storage of carbon.

More generally, it is becoming more and more important to give proper consideration, in policy-making circles, for potential mitigation measures within the agricultural sector. In this regard, the following have been singled out by the WG agriculture (which has been constituted under the scope of the European Climate Change Programme):

- Potential for reduction of nitrous oxide emissions from agricultural soils

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- Potential for sequestration of carbon in agricultural soils
- Potential for reduction of carbon dioxide emissions of fossil origin by providing renewable raw materials for the energy and industrial sectors
- Potential for mitigation of methane emissions from enteric fermentation; and
- Potential for abatement of methane and nitrous oxide emissions through manure management.

Among the measures listed above, at least the first 2 might be properly tackled through a strategy aiming at proper reuse of composted organic waste. In addition to the measures listed above, many other possible side-effects of compost application may be considered, and are of relevance in combatting climate change. We consider it important to mention at least:

- displacement of chemical fertilisers (which implies avoidance of GHGs associated with their production)
- reduction in the use of pesticides (which would imply avoiding GHG emissions associated with their production, as well as wider environmental benefits),
- improved tillage and workability (which might lead to less consumption of fuels) etc.

Finally, to the extent that, in some EU countries, climate change may lead to changes in patterns of rainfall, the improved structure of soils associated with the application of organic matter can help:

- a) to reduce the requirement for irrigation water in periods of drought; and
- b) increase the potential for soils to retain moisture in periods of rainfall, reducing the likelihood of flooding associated with moisture run-off.

This article seeks to advance some figures, and more importantly, to develop some strategic perspectives which might constitute *a preliminary assessment of the contribution of composting to tackle climate change issues, which, albeit somewhat difficult and affected by various uncertainties, cannot be neglected any more once we come to strategic environmental policy-making.*

When considering organic matter, or biowastes, only from an energetic standpoint, policy drivers run the risk of failing to consider the importance of Organic Matter (OM) in the soil both for the management of GHGs (for example, through the build-up of Soil Organic Carbon, SOC) and for the optimisation of cropping techniques and yields. *This is, arguably, a potential consequence of the Directive on Renewable Sources of Energy, which suggests the use of economic drivers for the energetic exploitation of organic waste, with no consideration of its role in carbon sequestration and in enhancement of soil and land fertility¹.*

In particular, from the standpoint of GHGs, assessments led in the past have neglected the important and positive effects of composting and compost application on:

- soil organic carbon and related sinks,
- its effects on improved uptake of nutrients,
- avoided energy uptake for the production of equivalent chemical fertilisers,
- avoided release of nitrous oxide from chemical fertilisers when allowing for the nutrient release from organic amendments.

All the points listed above need to be addressed, properly considered and hopefully quantified, at least through a tentative evaluation of the magnitude of their potential contribution.

In order to gain evidence on these aspects and to drive policy-making, for instance, in recent times DG ENV, has contracted a study on different options to manage biodegradable waste, whereby many of the aforementioned topics have been investigated (Eunomia et al., 2002).

It should be noted that issues related to soil organic matter may be increasing in significance as a consequence of the progressive changes in climate which we appear to be experiencing. A possible

¹ These points are highly stressed, for instance, by the Final Report of the WG "Organic Matter" in the context of the EC Consultation on the Soil Strategy, which reads:

"Concerning the use of renewable energy sources, it should be recalled that any combustion of organic matter (biomass) necessarily impairs possibilities of incorporation of the residues into the stable pool of organic matter in soils. The EU Soil Thematic Strategy should therefore tend to mitigate the potential negative effects of such drawbacks, in particular when using biomass that was not harvested for energy purpose".

and

"The implementation of the Kyoto Protocol for forestry and land use represents also a new incentive tool in order to fulfil the sustainable management of Soil Organic Matter (...) and the surface area involved will be millions of ha".

feedback mechanism associated with climate change is that the release of soil organic carbon may increase as the climate changes, so deepening the significance of addressing the decline in soil organic matter status (Bellamy et al., 2005). Not all of the carbon lost from soils is necessarily mineralised as carbon dioxide. Some may be leached into deeper soil layers and drainage waters.

Potential sinks for carbon in the soil through the use of organic fertilisers

This is probably the field of investigation where the most significant results are to be found. In general terms, organic matter is an issue of importance because of its influence on soil fertility, stability and structure, and the capacity of soils to retain moisture. Organic matter's decline in many European soils is threatening their capacity to remain fertile, and to continue performing their most essential environmental functions. The decline in soil organic matter is emerging as a key issue for EU policy. Looking at carbon stored in farm soils, it is very easy, indeed, to make a link with the organic fertility.

The Commission has indicated its intention, in the Sixth Environmental Action Programme (6EAP) to develop a thematic strategy on soil protection. The draft Council and Parliament decision on the 6EAP sets the objective of the promotion of a sustainable use of soil, with particular reference to preventing erosion, deterioration, contamination and desertification. EC communications have already noted that soil loss and declining fertility are eroding the viability of agricultural land. Accordingly, *the Communication from the Commission on Soil Protection, issued most recently, places particular emphasis on organic matter and establishes a goal of promoting the use of high quality composted products for such purposes as fighting desertification and erosion, avoiding floods, and promoting the build-up of carbon in the soil.*

Sequestration potential of agricultural soils

The IPCC clearly identified carbon sequestration in soils as one of the possible GHG mitigation measures for agriculture at an early stage (IPCC, 1996).

The loss of organic carbon in soils has been one of the major environmental consequences of industrial agriculture. Arable top soils in Europe commonly contain 1-3 % of organic carbon. ECAF (not dated) suggest that following tillage over a period of around 20 years, most agricultural soils will have lost about 50% of their organic carbon. The annual net release of carbon from global agricultural activities has been estimated at about 800 Mt/year, or about 14% of the carbon associated with fossil fuel burning (Schlesinger, 1995).

The most important result of the Bonn Conference for the agricultural sector was the possible unlimited use of agricultural land as sinks for carbon. A calculation made by DG Environment of the European Commission assumed that 20 % of the surface of agricultural land in the EU could be used as a sink for carbon. This would correspond to an absorption potential of around 7.8 million tonnes of carbon, which corresponds to around 8.6% of the total EU reduction objective. The EC Communication on a Soil Strategy also highlights the potential significance of sequestration. The Communication mentions, for instance, the fact that it has been calculated¹ that an increase of just 0.15% in organic carbon in arable soils in a country like Italy would effectively imply the sequestration of the same amount of carbon within soil that is currently released into the atmosphere in a period of one year through the use of fossil fuels.

This should be compared to the somewhat worrying decline in soil organic matter over past decades, the magnitude of which has been, in many areas, in the order of some percentage points, and which has led to soil organic matter content falling below 2% in many soils. According to the European Soil Bureau, nearly 75% of the total area analysed in Southern Europe has a low (below 3.4%) or very low (below 1.7%) soil organic matter content. The problem is, however, not restricted to the Mediterranean. Figures for England and Wales show that the percentage of soils with less than 3.6% organic matter rose from 35% to 42% in the period 1980-1995. In the Beauce region south of Paris, soil organic matter has halved in 16 years. These figures suggest a net loss of organic carbon from soils, some of which can be expected to have occurred through mineralization of carbon, representing a net flux of GHGs from soils to the atmosphere. However, if one looks at these figures from the opposite standpoint, one sees an opportunity to deliver win-win scenarios through the management of organic wastes. *A huge opportunity exists to lock-up considerable amounts of carbon whilst contributing to the restoration of soil fertility and health.*

Many surveys have lately been focusing on measures regarding the application of composted organic fertilisers. Composting can contribute in a positive way to the twin objectives of restoring soil quality and sequestering carbon in soils. At the same time, in the EU, the waste management sector is being challenged, under the scope of the EC Directive 99/31 on the Landfilling of Waste, to achieve targets

¹ Speech by ^{Prof.} P. Sequi at the Compost Symposium, Vienna, 29-30 October 1998

for the reduction of biodegradable municipal waste to be landfilled. This suggests there is considerable merit in the waste management sector seeking to ensure that opportunities for recovering organic materials in a manner suitable for application to soils are considered as a priority in seeking to meet targets for reducing the amount of waste sent to landfill.

“Sequestration” and “build-up”: a matter of methodology

Proper application of organic fertilisers in agriculture, besides the adoption of proper cropping and tilling techniques, can have a positive effect on soil carbon levels. Applications of organic matter can lead, depending upon the rate of application and other factors, either to a build up of soil organic carbon over time, or a reduction in the rate at which organic matter is depleted from soils. In either case, relative to the situation where no organic matter is applied, a beneficial effect may be experienced in respect of the quantity of organic matter in soils.

Many assessments of waste management options adopt a life-cycle assessment approach to the comparative appraisal. The assumptions contained therein are crucial for the outcomes of the analysis insofar as GHG emissions from soils are concerned. Life-cycle assessment approaches have tended to suffer from several shortcomings. One of these is their failure to take into account the dynamics – or the dimension of time – in the assessment of environmental outcomes. In waste management systems, this is of particular significance when comparing biological processes with thermal ones. This is because the degradation of biomass tends to occur over an extended period of time (over 100 years), whilst thermal processes effectively lead to emissions of carbon dioxide instantaneously.

In this context, it becomes important to understand the significance of two issues:

Life-cycle approaches have to consider at what point in time one draws a cut-off to determine which emissions ‘count’ and which do not. Few take that point to be ‘an infinite period ahead in the future’. This means that the cut-off point necessarily becomes an arbitrary one. Many analyses assume that the IPCC cut-off for modelling – 100 years in the future – is a relevant time horizon. Yet one can reasonably ask why this is considered the relevant period for the IPCC modelling, not to mention, why it should be considered relevant for a comparative analysis of waste treatment options (which is not what the IPCC is involved in). Why not 3 years? Or 10? Or 35? Or 50? There is, in short, no logic behind the use of this arbitrary cut off. Why do emissions at any time before that date ‘count’, equally, but every emission after that point ‘does not count’. The use of ‘sequestration’ values (un-emitted carbon dioxide at the cut-off point) does not adequately rectify the issue for reasons explained below;

The fact that all emissions - in life cycle assessment – count equally irrespective of the timing of their emission has to be questioned. There are logical and methodological reasons for questioning the adequacy of this approach. The pace of climate change is, it would seem, faster than was hitherto thought to be the case. What does this imply for the time profile of emissions? What does this imply for the choice between processes which emit carbon dioxide over an extended period of time, and those which emit all carbon dioxide on day one of the process? Life-cycle assessment, as conventionally applied, offers the analyst zero insight on this potentially critical point. Indeed, although several practitioners understand the potential relevance of discounting, as employed in cost-benefit analysis, some have sought to propose zero, or even negative, discount rates on grounds of sustainability without apparently understanding what their proposals might imply for the functioning of the economy.

Where compost is concerned, carbon dioxide is emitted first, in relatively large quantities, in the intensive phase of the process, and then, at a slower rate, in the maturation phase. Following application of material to soil, the initial rate of emission will depend upon the degree to which the compost has been matured prior to application to soil. However, once applied to soil, the rate of emission declines. Depending upon what assumptions one makes in the analysis, the application of compost to soil is either a ‘time-limited sequestration process’ (if one assumes that biogenic emissions of carbon dioxide are not to be counted in the analysis, in which case, the time perspective becomes critical) or a management process where emissions of carbon dioxide simply occur over an extended period of time. However, as has been correctly stressed by many recent surveys (see for instance: Smith et al. 2001), estimating a precise lifetime for soil organic matter derived from compost addition is very difficult, because of the large number of inter-converting pools of carbon involved, each with its own turnover rate, which is in turn determined by local factors such as soil type, temperature and moisture (hence the potential feedback mechanisms associated with changing temperature and rainfall patterns in the wake of climate change). Although a great deal of valuable information now exists on the turnover of soil organic carbon, the question of assigning a typical average value for the persistence of carbon applied to soils in compost remains somewhat problematical.

Life times of various pools of soil organic carbon ranging from 20 to 2000 years have been proposed as means of setting boundaries by the US EPA. Isotope studies (Carter, 1999) have shown that turnover times differ widely for different fractions of soil organic matter, ranging from less than a year

for microbial biomass to between 5 and 1,000 years for organic matter associated with silt and clay particles. Applying first-order decay kinetics (which are widely used in this field), this global average suggests that only 2% of the carbon applied to soil today would remain in the soil organic matter in 100 years time.

Smith et al (1997) have reported summary results from several long-term field experiments in which sewage sludge, animal manure and cereal straw had been incorporated annually into the top layer of soil. They derived linear correlations between the organic matter addition and the annual increase in soil organic carbon, which, if a steady state has been reached between carbon input and soil organic carbon, allows the amount of added carbon surviving in the soil for a given period to be calculated. Using the equations provided by Smith et al and assuming a carbon content for manure and sewage sludge of 20% results in estimates of 9 and 6 % as the proportion of added carbon persisting for over 100 years.

Despite all the findings listed above, which tend to make the potential contribution of compost (and in broader terms, of organic soil improvers) to sequestration particularly small, and almost negligible over a hundred year period, as suggested above, what matters is not 'what is left after 100 years' but how emissions of carbon, and the retention of carbon in soil, change over time.

Climate models are sufficiently sensitive to the dynamics of emissions so as not to be indifferent to a situation in which every unit of carbon dioxide likely to be emitted in the next 100 years is emitted today, and the situation where emissions occur continuously over the one hundred year period. Indeed, if there was no such sensitivity within these models, the case for early, as opposed to later, action might be difficult to make as long as action occurred within a 100 year timeframe.

We think the focus ought to shift from whether something simply does or does not act as a 'net sequester of carbon', to *how much carbon is emitted (and how much kept in the soil) over time under different practices and scenarios, since the sequestration of carbon in soils is always 'time-limited'*.

Organic fertilisation does not result in the permanent and irreversible locking up of all carbon in compost. What organic fertilisers can do is *reverse the decline in soil organic matter which has occurred in relatively recent decades through contributing to the build up in the stable organic fraction in soils, and having the effect, in any give year, of ensuring that carbon which might otherwise be emitted as carbon dioxide is held within soil*). It is also important to realise that whilst the debate concerning 'sequestration' has emerged as a topical one in the wake of the debate on climate change, the role played by soil organic carbon is far more complex, and potentially far more important, than the single role played in terms of carbon sequestration.

The application of organic matter on a regular basis causes the accumulation of organic matter, but at some point, rates of application and rates of loss are likely to equalise, leading to a steady-state condition in the long run. The steady-state level – at which mineralisation of organic matter offsets the annual accumulation of organic matter - depends upon factors such as climatic and cropping conditions, the annual rate of application of organic matter, and the nature of the organic matter applied. However, the overall potential for increasing the carbon content of soils can be considerable in the short and medium term, whilst the system is moving towards a steady-state condition. *This means that the time-limited sequestration of carbon in soils can play a significant role in the achievement of targets for reducing greenhouse gas emissions over a period of years or decades.*

The simplified modelling shown hereafter, based on dynamics among different pools of organic matter in the soil and the atmosphere, might for instance lead one to conclude that, depending upon starting conditions and climatic and cropping situations, the build-up of organic matter in soils over 50 years might enable a net accumulation of between 1 and 3 % of soil organic matter, corresponding to an estimated increase of between 0.58% and 1.74 % soil organic carbon. Compared to the figures suggested above, this quantity could offset 4 to 12 years of annual emissions of carbon dioxide.¹

The assessment of this potential accumulation becomes even more impressive if one makes the comparison relative to a baseline scenario in which there is no application of organic fertilisers, nor any practice to increase or keep the quantity of organic matter in the soil, which might be considered to have been the case in many farmlands throughout last decades, and might be a scenario driven by the consideration of biomass only as a substitute for fuel. Proper attention therefore ought to be paid to what seems to be a primary tool to tackle greenhouse gases.

¹ i.e. around 0.15% more carbon in soil to offset the yearly CO₂ – eq. emission, see previous footnote.

A preliminary assessment of lock-up of carbon through a simplified model

Usually dynamics related to the build-up of carbon in soil are neglected in policy making in respect of climate change, notwithstanding the considerable body of scientific evidence that has been developed. Long-term trials demonstrate the capability of soil to store organic carbon over long periods, though the complexity of related dynamics makes it difficult to model, in a quantitative manner, the effects.

To provide a preliminary assessment of the potential contribution of sequestration of SOC to management of global climate issues, we have modelled the dynamics of its application and build-up on the one side, and its mineralization, or loss, on the other.

In a simplified model, three pools of organic carbon are available for microbial utilisation:

1. The “active” soil fraction (representing short-term sequestration of carbon – provides source of energy for microbes, and soil carbon and nitrogen supply necessary for amino acid synthesis);
2. The “slow” or “decomposable” soil fraction (of great importance to developing good soil structure. This is disturbed by cultivation and other disturbances and provides a source of carbon for biological digestion by microbes, so linking to the active pool. It can be viewed as mature compost); and
3. The “passive” soil organic fraction (this has a turnover time of the order 100 to 1000 years and is relatively resistant to oxidation processes. It acts as a ‘cement’ that binds particles).

Only the first two of these pools contains carbon in a readily available form for microbial utilisation. The last pool contains carbon in a highly stable form. Some microbes can utilise this pool so depletion does occur. It can also be replenished from active and slowly decomposable fractions. It is the fact that this passive pool of carbon can be maintained or increased that leads to the idea that the passive pool can act to ‘sequester’, in a time-limited fashion, carbon in the soil. This long turnover appears to imply that this carbon is only released into the atmosphere very slowly. It will be kept within the soil for a long period of time, hence its potential value in mitigating the effects of climate change.

The application of compost is assumed to lead to the readily available carbon being mineralised at y% whilst x% of the readily available organic carbon is converted to stable organic matter. Of this stable organic matter, some carbon (z%) is mineralised, but at a much lower rate than that at which the readily available matter is converted to stable organic matter. Consequently, application of organic matter to soil can act to increase soil organic carbon levels (though as we shall see, the degree to which this occurs varies according to the choice of the different parameters chosen, the rate of application of compost and the baseline level of organic matter in the soil).

The model can then be run through the application of values for X, Y, Z as found in literature for mineralisation of both stable and readily available OM, and for humification of readily available organic matter. For instance, referring to Z, one could consider the half-life (t_{1/2}) times of humic carbon reported in literature, ranging between some decades and more than 1,000 years. Solving the equation:

$$0.5 = e^{-(z \times t_{1/2})} \quad \text{where } t_{1/2} \text{ is the calculated half-life.}$$

Different typical values of z are available.

In Figure 1, the response curves are shown using the following conditions:

X = 30%, Y = 15%, Z = 1% (t_{1/2} time at some 68 yrs.), and with an initial organic matter concentration of 4%, deemed to be typical of Northern European areas.

Such outcomes are generally consistent with long-term field trials which have already been run by the Rothamstead Agricultural Experimental Centre for more than a century, surveying long-term effects of different agronomic practices about the build-up or decrease of organic matter in the soil. Outcomes from Rothamstead (Table 1) clearly demonstrate that avoiding organic fertilisation determines a big loss of organic matter in the soil, which causes a net transfer of Carbon (as carbon dioxide) to the atmosphere. The application – continued with time - of organic soil improvers (manure in the trial, but outcomes would hold similar with compost) makes it possible to keep concentrations of Carbon at those levels that are typical of natural background concentration - or to increase the concentration in those soils already depleted. This makes the soil a powerful “sink” for Carbon. The numbers suggest that soils where manure was added showed soil organic carbon levels 1.34% higher than unamended soils, and 1.13% higher than soils amended with chemical fertilisers over a 50 year period. This is clearly significant given the evaluations reported above regarding carbon being lost from soils, and the increasing amount of carbon dioxide in the atmosphere.

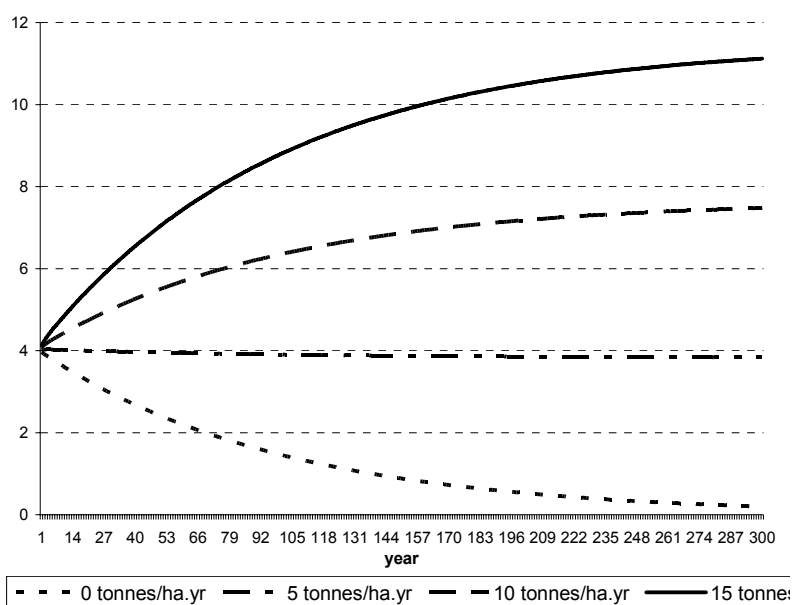


Figure 1. Effect of different rates of compost application on soil organic matter levels (as a percentage of soil weight) in time.

Table 1. Findings of long-term field trials in Rothamstead

Type of vegetation or cropping	% C
Pasturelands	1.52
Under a forest	2.38
After cropping wheat continuously for 50 years, 1893	
No manure added since 1839	0.89
Only chemical fertilisation since 1843	1.10
14 tonnes manure yearly since 1843	2.23

Reduced use of chemical fertilisers and related effects

Unlike mineral fertilisers, the use of organic fertilisers, although containing nitrogen (N), phosphorous (P) and potassium (K) does not provide a specific amount of N, P or K that will be immediately available to the growing plant. Compared to mineral fertilisers, they provide lower levels of N, P and K. However, their addition can provide essential trace minerals to the soil (calcium, sulphur, iron, boron, molybdenum and zinc) that are not supplied when mineral fertilisers are added.

Furthermore, the application of organic fertilisers can enhance nutrient uptake by reducing leaching of minerals. Losses of nutrients by leaching can be reduced by increasing the soil organic matter content. Some nutrients in the water soluble form required by plants are readily leached from mineral soil particles, whereas they are effectively held on the surface of humified organic matter.

Replacement of alternative nutrient sources

When organic fertilisers are applied to the soil, they may displace nutrients which are otherwise applied through synthetic fertilisers.

We assume in the analysis that nutrients are displaced on a one-for-one basis from the perspective of plant uptake. Taking the view from the perspective of the plant is important since the rate at which nutrients are leached from humus is lower than the rate at which they might be leached from synthetic fertiliser. *As such, more of the nutrient in synthetic form would be required to be applied to have the equivalent mineral fertilisation effect.* The assumption of 'one-for-one' displacement is an unrealistic one to the extent that one is implying a perfect optimisation of the replacement process. On the other hand, the situation is more likely to approach the ideal one once farmers are well informed about the

nutrient content of the matter being applied (which is anyway happening more and more frequently, above all in those Countries with a longer tradition in composting and compost application).

We have assumed that 10 tonnes of dry matter is applied through organic amendment per hectare. This is equivalent to approximately 16.7 tonnes of composted manure or other composted materials (CM, dry matter content 60%) or 25-33 tonnes of "traditional" manure (TM, 30-40% dry matter). Specifically focusing on CM, we assume further that this material has the following composition in terms of nutrients:

Nitrogen:	1.5% dry matter
Phosphorous (as P2O5):	1.0% dry matter
Potassium (as K2O):	1.2% dry matter

In order to run a test assessment we assume a mineralisation rate of the nutrients in CM to be 30% for all nutrients. Such a figure, which is fairly high, might be deemed appropriate for weather and cropping conditions typical of Southern Europe (warm weather, intensive cropping, high tendency to mineralise any added organic fertiliser). This determines the time profile of the displacement effect.

In order to allow for the part of chemical fertilisers which is leached, we also considered a "loss rate", which actually increases the displacing potential of organic fertilisers. For synthetic fertilisers, we assume a loss rate of 23% for nitrogenous fertilisers (Hydro agri Europe, 1995). This means that more nutrient has to be applied in a given year in the synthetic form than would be available in mineralised form from the composted materials. For an application of 10 tonnes dry matter per annum in one year, the N displacement would follow the evolution set out in Table 2.

Table 2. Evolution in N displacement associated with 10 tonnes dry matter of compost applied to farmland

Year	Displacement potential N (kg)	Cumulative Displacement (kg)
1	58.4	58.4
2	40.9	99.4
3	28.6	128.0
4	20.0	148.0
5	14.0	162.1
6	9.8	171.9
7	6.9	178.8
8	4.8	183.6
9	3.4	186.9
10	2.4	189.3

Avoided emissions from production of fertilisers

The use of manure and composted manure as a replacement for fertiliser will thus displace the pollution and other externalities associated with fertiliser production, including the energy uptake, that is important as to climate change issue. From this standpoint, many further calculations may be developed.

There is substantial evidence that, unlike fertiliser, the application of organic amendments also improves aspects such as soil structure, and that a higher proportion of the nutrients are available for uptake by plants. There is very little quantitative data in this area and therefore it is likely that analyses of this type will underestimate the benefits from application of organic fertilisers.

As to the potential savings for energy and greenhouse gases implied by the displacement of chemical fertilisers, some input data and a preliminary assessment is offered here. Fertilisers vary a great deal in terms of nutrient content and therefore the externalities will vary also. We considered data for the production of N:P:K fertiliser because this is one of most widespread in terms of use, and the most readily available from a data perspective. Again because of data availability, we calculated the externalities associated with the production of one tonne of 15:15:15 NPK fertiliser (i.e. 150kg N, 150kg K2O and 150kg P2O5).

Data based on Best Available Technologies from EMFA (European Fertilisers Manufacturing Association) were used to characterise emissions associated with fertiliser production via the mixed acid route. There are three further distinctions within this route (granulation with a pipe reactor system, drum granulation with ammoniation and digestion). The data concerning emissions have been taken from those for the 'digestion' process because it is the only process for which this study has obtained data associated with all the required raw materials. The EMFA booklets suggest that these three processes cover the majority of NPK fertiliser production in Europe. The EMFA booklets provide gaseous emissions and energy consumption data associated with sulphuric acid, nitric acid,

phosphoric acid and ammonia production, the base acids used in mixed acid production of NPK (15:15:15).

Unfortunately, we have not been able to obtain quality data for extractive processes. We know anyway that mining phosphate rock is an energy intensive activity and approximately 3.3 tonnes of phosphate rock are required to produce one tonne of P₂O₅ (Bocoum and Labys 1993). Energy use for producing phosphate rock has been estimated at 73.5 kWh/tonne (UNEP and UNIDO, 1998). Additional energy consumption for phosphate fertiliser may be attributed on this basis. Because we have no information concerning emissions in potash production, *the emissions data for K₂O are likely to grossly understate the environmental benefits of displacement effects*. A study by Nolan-ITU (2004) also recently estimated damages associated with phosphate rock extraction.

It is important to note that these externalities are associated with Best Available Technologies for both new and existing plants. Therefore the gaseous emissions and energy requirements are likely to be underestimated as not all plants will be using Best Available Technologies. Technological improvements in the future however are likely to mean that these levels will become more similar to emission levels observed in practice.

On the basis of such input numbers, the emissions and energy data have been calculated and are summarised in Table 3. Such figures for emissions, and for energy uptake (which can be converted into CO₂-eq taking into account the typical energy mix and its average CO₂-eq intensity in each Country) can be considered alongside the power of organic matter to reduce applications of chemical fertilisers, as calculated, for instance, in the previous section.

According to our preliminary calculation, we may for instance briefly highlight that *a single compost application of 10 tonnes d.m./ha, which has a potential displacing power of some 190 kg N, might therefore allow an overall saving of electricity of 160 to 1590 kWh, not to take into account displacement of P and K, nor the CO₂-eq. related to other emissions (e.g. N₂O, see the following section)*.

Table 3. Emissions data for fertiliser manufacture

Emission (tonnes)/kg nutrient And unit E uptake	N		P ₂ O ₅		K ₂ O	
	Low	High	Low	High	Low	High
CO ₂	2.57E-03	2.57E-03	0	0	0	0
NO _x (as NO ₂)	4.09E-06	2.14E-05	6.67E-07	6.67E-07	6.67E-07	6.67E-07
N ₂ O	9.28E-06	3.52E-05	0	0	0	0
NH ₃ (as N)	4.44E-07	4.44E-07	4.44E-07	4.44E-07	4.44E-07	4.44E-07
Fluoride (as F)	4.44E-08	4.44E-08	7.11E-08	2.04E-07	4.44E-08	4.44E-08
Dust/particulates	4.44E-07	4.44E-07	7.11E-07	1.24E-06	4.44E-07	4.44E-07
SO ₂	4.37E-07	1.44E-06	4.30E-07	1.43E-06	4.30E-07	1.43E-06
SO ₃	2.15E-08	8.60E-08	2.15E-08	8.6E-08	2.15E-08	8.6E-08
CO	1.29E-08	1.29E-08	0	0	0	0
Energy Use (drying) (MJ)	5.78E-04	5.78E-04	5.78E-04	5.78E-04	5.78E-04	5.78E-04
Elec Use (kWh)	8.37E-05	8.37E-05	4.82E-04	4.82E-04	8.37E-05	8.37E-05

Reduction of N₂O emissions from nitrogenous fertilisers

Fertilisation of crops contributes to the emission of greenhouse gases, especially through the emission of nitrous oxide (N₂O) from soils. This is a result of incomplete transformation of ammonia to nitrate (nitrification) and/or the incomplete turnover of nitrate to nitrogen gas (denitrification). Measures aimed at reducing nitrate content in waters may result in declining nitrous oxide emissions.

It is generally accepted that the application of nitrogenous fertilisers increases fluxes of N₂O. Therefore, the reduced application of N fertilisers, once one accounts for the N-release by organic materials, might influence the release of N₂O. Different fertilisers appear to be more or less susceptible to the loss of nitrogen as nitrous oxide. The emissions depend upon temperature, soil moisture, fertiliser type, fertiliser amount, the timing and mode of application, and the type of soil and crop cultivated (see, for example, McTaggart, Ball and Watson, 1998). Ammonia products appear most susceptible, with anhydrous ammonia and aqua ammonia losing between 1% and 5% of nitrogen as nitrous oxide. Other products such as sodium nitrate appear to lose much less nitrogen in this way (Lashof and Tirpak, 1990). A Dutch study cites figures for N₂O losses as between 1 and 3% of mineral N applied (Mosier, 1993).

Reduction options for N₂O generally rely on:

- the reduction of nitrogen inputs to soils through enhanced fertiliser use efficiency and
- a better accounting for N in manures and other humified products (including compost) applied to soil, so that N of chemical fertilisers can be displaced by slow-release N, whose kinetics make it much less prone to producing N₂O

Once it comes to the assessment, one could – perhaps conservatively - assume a unit loss as N₂O of 0.05% to 0.5% of nitrogen applied as chemical fertiliser relative to the situation where compost is applied. These assumptions can be matched with the N replacement figures for the compost as outlined in earlier sections and Table 2. The net effect is that over a 20 year period, an application of 10 tonnes dry matter of organic material with 1.9% N content might offset nitrous oxide equivalent to between 60-600kg CO₂. This is not a major effect, though nonetheless, it is potentially significant, not least since our understanding of the key parameters are poorly developed at present.

Economic drivers and funding programmes

Some noteworthy attempts to internalise the positive externalities associated with the application of organic matter to soils are to be found in some Regions of Italy, where under the scope of Rural Development Plans (2000-06) (Reg. CE 1257, on sustainable agriculture), farmers receive financial support in lieu of the application of organic fertilisers, and in particular, composted products:

- Region Emilia Romagna has already been paying, for a period of a few years, 250.000 ITL/ha (some 130 €/ha) to make use of compost, and so promote the build-up of soil organic carbon in depleted soils; and
- Region Piemonte pays 220 €/ha for farmers to use up to 25 tonnes d.m. on depleted soils over a 5 year period (in order to take into account crop rotation).

Such grants might be considered a precedent, when it comes to environmental policy-making and economic instruments for environmental policy, for driving agronomic practices – and the related waste management practices - towards a more sustainable approach to the apparently related issues of climate change and soil quality.

Other side effects of compost application on GHGs

As discussed above, many other side effects of organic fertilisation are likely to have implications for greenhouse gas emissions and the mitigation of climate change-related impacts:

- reduction in the use of pesticides (which would imply avoiding GHG emissions associated with their production, as well as wider environmental benefits);
- improved tilth and workability (which might lead to reduced consumption of fuels);
- reduced requirement for irrigation water in periods of drought; and
- increased potential for soils to retain moisture in periods of rainfall, reducing the likelihood of flooding associated with moisture run-off.

Furthermore, another net benefit as to GHGs could stem from the use of compost as a peat substitute in horticulture. The use of peat results in the mineralisation of the carbon kept in peat bogs (which might be treated as “fossil carbon” due to its long-term storage), so making a net positive contribution to global warming.

The greenhouse gas emissions associated with peatbogs are extremely complex, and they change once the process of development (for extraction) occurs. In northern peatlands, the anaerobic conditions and cold temperature result in increased sequestration of carbon (relative to other wetlands).¹ Unperturbed peatbogs, whilst they may act as a sink for carbon, may also emit methane. However, as long as they are unperturbed, they most likely retain a balance between methane emissions and carbon sequestration.

Drainage and degradation of peatlands increases carbon dioxide emissions. It also increases nitrous oxide emissions significantly (Roulet et al., 1993; Regina et al., 1998; Schlesinger, 1995; Freeman et al., 1992). It has been estimated that peatlands contain between 329 and 528 billion tonnes of carbon (equivalent to 1,200-1,900 billion tonnes of carbon dioxide). Unless the bogs are disturbed by

¹ Wetlands store carbon in short- and long-term reservoirs. Storage occurs when primary production is high and exceeds the rate of decomposition, or when the rate of decomposition is slowed by a process known as anoxia, and cold temperatures (leading to accumulation of undecomposed organic matter).

extraction, drainage or other human intervention, much of the carbon will remain in-situ for near geological timescales.

Drainage of peatlands and other wetlands acting as carbon reservoirs will result in the oxidation of the organic matter, releasing it to the atmosphere as carbon dioxide, methane and other greenhouse gases. Conversely, restoration or creation of new wetlands may provide additional carbon sinks (Environment Canada, 1998).

Conclusions

From science-based evidence the following conclusions may be drawn:

- GHG-mitigation measures related to LULUCF (Land Use, Land Use Change and Forestry) may imply comparatively cheap solutions to provide for remarkable GHG savings;
- Composting and the use of composted products ought to be considered among such measures since they imply a time-limited sequestration of carbon which needs to be recognised by policy makers, whilst also indirectly reducing emissions of GHGs through reducing demand for, and application of mineral fertilisers, pesticides, peat, etc.)

The following also ought to be stressed:

- Compost can only store carbon temporarily in soils. The carbon will be released, in the long run, into the atmosphere. As already argued, however, the time horizon over which the “progressive build-up” of carbon in soils occurs may have a comparatively important duration. This may help reduce emissions of carbon dioxide in the short- to medium-term, essentially ‘buying time’ for further adaptation strategies to be developed. It seems appropriate, therefore, for life cycle assessment studies to continue to ignore the time profile of emissions of greenhouse gases. Instead, insights from cost benefit analysis, where time has traditionally played an important role (through the concept of discounting), are likely to be especially relevant. The reader is referred to other research by the authors for further explanation of the issue (see Eunomia et al., 2002; Eunomia, 2006; Eunomia, 2007);
- There is an outstanding opportunity for additional scientific research on the dynamics of carbon and nitrogen (so as to inform understanding of nitrous oxide fluxes) in soil (including those of ‘displaced products’). The same applies to other potential benefits of compost, including the effects on pesticide use, and the effects on water retention and irrigation demand. These research efforts should enable us to understand, in greater depth, the effects of applications of compost and other organic amendments, thereby supporting the rational design of policies to engender wider use of compost in the battle to maintain soil quality and reduce climate change emissions.

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Role and importance of compost use in vegetable and other horticultural crops to sustainability

Robert Paulin¹, Peter O'Malley¹

Keywords: compost; soil quality; standards; planning

Abstract

Investigations into the use of compost to improve productivity of a range of horticultural crops and to develop them as sustainable compost markets, commenced over 10 years ago. The work has increasingly focussed on vegetable production and on quantifying management benefits such as fertiliser savings as well as improvements to soil quality.

Factors limiting the adoption and regular use of compost have been identified. They include reducing compost cost to farmers and implementing minimum standards for the application of all organic materials to land.

By acknowledging the contribution that rural zones make to the wider community through managing wastes including recycled water, supplying safe fresh food and contributing to a range of other social and environmental benefit, changes to land use planning that will protect important areas from continued urbanisation are also being sought.

Introduction

Work into the use of compost to improve horticultural productivity and to develop these industries as sustainable compost markets commenced in 1996. These objectives have remained unchanged however the initial focus on the role of compost has shifted to considering its importance in managing soil quality. This shift is a recognition of the importance of soil organic carbon and the need to develop production systems that maximise its functional levels in horticultural soils.

Recent work has focussed on quantifying the benefits of compost to vegetable production (HAL Report 2004). In preparing the report, a discussion paper 'Compost production for agricultural use – issues for the developing recycled organics industry' was prepared. This has provided input to policy and regulations aimed at assisting the developing recycled organic industry and the production of products that provide maximum benefit to soil quality and agricultural production, as well as to better manage environmental and social issues that are associated with current organic waste management and agricultural practices. The paper supported the development of a national soil protection strategy, identified the need for standards to govern the application of all organic materials to land and identified options for reducing the cost of compost to agricultural markets.

Land use planning considerations identified the need for strategic processes that give rural land precedence over urban areas, effectively reversing the current situation.

Materials and methods

The recent vegetable work has been conducted on coarse sandy soils using compost made by a single supplier from urban greenwaste and chicken manure. Two replicated trial sites were developed and work continues to investigate maximising soil organic carbon levels and nitrogen mineralisation.

The issues identified for developing agricultural compost use provided significant direction to a Ministerial working group into standards for composts derived from mixed solid wastes and resulted in a report on 'Standards for Organics (including Compost) Applied to Land'. This report also identified the need to develop policy similar to the European Union Soil Protection Strategy, along with the need to reduce the cost of compost to farmers and for policy to direct source separation as the principal waste collection objective.

Results

Improvements to soil quality are presented in Table 1 and some results indicating the potential for increased organic soil carbon to improve productivity, is provided in Table 2. Detailed results are available in the HAL Report and a paper presented to the US Composting Council Conference in January 2007, provides a summary of the findings to late 2006.

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Table 1. Soil properties after seven 30m³/ha compost applications

Treatment	Soil carbon (%)	Volumetric water (%)	Bulk density (t/m ³)	CEC (c mole/kg)	pH (CaCl ₂)	Total N (%)
Control	0.513	10.124	1.429	2.706	5.85	0.027
Compost 30m ³ /ha	0.746	11.995	1.365	6.168	6.8	0.048
Compost 60m ³ /ha	0.911	14.174	1.321	8.533	6.85	0.065
LSD (P<0.05)	0.100	0.412	0.023	1.08	1.79	0.005

Table 2. Carrot yield in response to soil organic carbon and nitrogen fertiliser application

Soil organic carbon (% dry wt)	Applied N (kg/ha) for maximum yield	Harvested yield (t/ha)*	
		Total	Marketable
0.4	290kg/ha	75	44
0.9	90kg/ha	78	63

* LSD (P<0.05) 9.7t/ha

Interim standards released following the report of the Ministerial working group have been rejected largely because they were proposed as voluntary standards that did not include biosolids. The final outcome from this process is pending.

Discussion & conclusions

Fertiliser savings associated with the use of good quality compost is sufficient to meet around two thirds of compost application costs. However despite improvements to soil moisture holding, anticipated savings to irrigation have not been achieved to date. It is likely that improvements to soil organic carbon levels and to the soil hydraulic conductivity of these coarse sands, has been insufficient to reduce the need for daytime irrigations over the 8 to 9 month period of high evaporative demand that is experienced each year.

Amongst growers likely to use compost, the lack of standards is reducing its ability to compete against cheaper manures. Further compost cost necessitates large capital outlays prior to crop establishment that significantly increase financial risk, particularly when most crops have narrow profit margins.

Despite these considerations, there is an increasing awareness amongst growers of the potential to increase productivity by improving soil quality. Improvements to carrot productivity (Table 2) associated with increasing soil organic carbon levels supports these views.

Ongoing work will therefore seek to engage growers in maximising soil organic carbon levels through the development of improved management practices and will continue to encourage appropriate policy development that includes implementing standards for organic material application to land.

With respect to land use planning, a major limitation to bringing about change to the current planning paradigms will be difficulties in converting the associated benefits into values that can be used in an economic model that accounts for all of these indirect benefits.

Acknowledgments

Our colleagues and numerous collaborators in the horticultural and Recycled Organics industries.

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Substitution of peat with garden waste compost in growth media preparation: a comparison from a LCA-modelling (EASEWASTE) perspective

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Key words: compost, peat, garden waste, LCA, EASEWASTE

Abstract

Environmental effects of diluting peat with compost in growth media preparation have been assessed using EASEWASTE for a 100 years time horizon Life Cycle Assessment (LCA). Danish average Life Cycle Inventories for peat and garden waste compost have been defined. Leaching tests on the two materials have been performed to define the impacts on the environment once they are used on land. Results show that compost performs better with regards to global warming, nutrient enrichment and acidification. The assessment on the toxicity impacts shows controversial results, influenced by the heavy metals contents of compost and of the mineral fertilizers replaced.

Introduction

Plant production industry uses large quantities of peat for preparing growth media. Peatlands are significant reservoirs of carbon, which is released back to the atmosphere once peat is used as a soil amendment and degraded. Excavation of peatlands, also including the fuel used for the machinery, may pose an impact on the environment.

Compost can substitute, or at least dilute, peat in growth media preparation. Advantages of compost: it is carbon neutral, it is produced locally, and it contains nutrients which could potentially replace mineral fertilizers. Disadvantages of compost: it has a higher content of heavy metals compared to peat, there is a potential for leaching of nutrients, there is a potential for ammonia evaporation.

Materials and methods

Life Cycle Inventory for average peat used in Denmark is based on literature data, mainly from Clearly et al. (2005) and Finnish Environment Institute (2004), and includes the 4 life cycle phases of peat: preparation of peatland, extraction and processing of peat, transportation, and use on land. Life Cycle Inventory of compost is based on data collected and included in the EASEWASTE database. Collection and transportation of waste are not considered. Compost from garden waste is assumed to be produced in a windrow composting plant.

The literature data were supplemented with laboratory data. Different types of compost were collected and sent for complete physical-chemical characterization. Leaching of metals, organic carbon, chloride, bromide, nitrate and sulphate from all the collected samples were measured with L/S 10 leaching tests. Methods and results of the leaching tests are reported in Boldrin et al. (2008).

The two inventories were compared by means of EASEWASTE, an LCA model developed for integrated solid waste management (Kirkeby et al., 2005). The EDIP methodology was used for the impact assessment.

The functional unit was defined as a certain volume of growth media, it was assumed that compost replaced peat on 1:1 volume basis. According to the different densities, in average 1 ton of compost is substituting 285 kg of average peat used in Denmark. N, P, K nutrients contained in compost were calculated as offsetting mineral fertilizers production. Utilization ratios were 20 % for N, and 100 % for P and K. It has also been considered that about 15 % (value for Danish meteorological conditions and soil composition) of carbon contained in compost is still bound to soil after 100 years (time horizon of the assessment) and can be considered as removed from the system (Christensen et al. 2008). Leaching of compounds is assumed to have impact on groundwater.

Results

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Figure 1 presents the potential non-toxic environmental impacts for compost (1000 kg) and peat (285 kg). With regards to global warming, compost performs better because it is carbon neutral and part of its carbon is bound to soil after 100 years, while all the fossil carbon contained in peat is assumed released to the atmosphere. Nutrient enrichment (eutrophication) results are mainly determined (for compost) by the offsetting of P fertilizers, the production of which implies a relevant discharge of phosphate into freshwater bodies. Emissions of NO_x during combustion of fossil fuels in machineries and transportation means are the main contributors to eutrophication and acidification during the life cycle of peat.

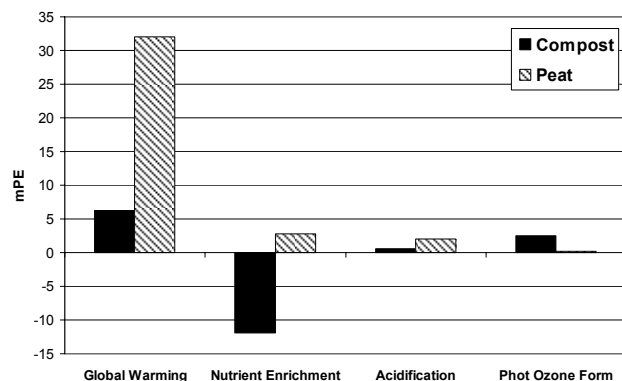


Figure 1: Potential non-toxic environmental impacts for compost and peat.

Figure 2 presents qualitative results for the potential toxic environmental impact assessment. It can be concluded (human toxicities) that there is a benefit in replacing mineral fertilizers (especially P), cause the environmental load of the metals released during the production is being avoided. Compost leachate has 3-20 times higher concentrations of metals and other compounds than the peat leachate. Therefore, compost has a potential impact on groundwater resources 10 times bigger than peat when used on land. The higher heavy metals content of compost explains the bigger impact with regards to the other impact categories.

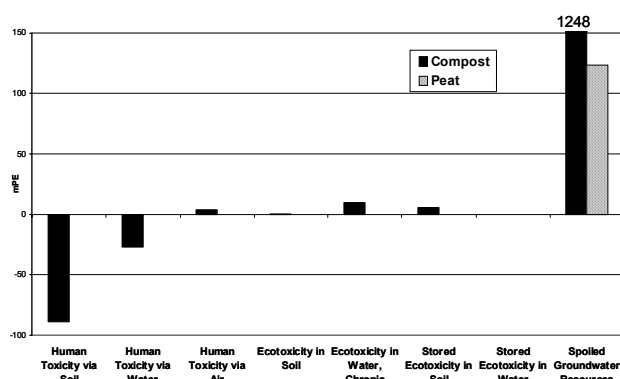


Figure 2: Potential toxic environmental impacts for compost and peat.

Conclusions

The substitution of peat with compost in growth media has some environmental benefits. The biogenic origin of the carbon contained in compost improves the carbon footprint of growth media. NO_x emissions from use of heavy machineries are also prevented, with benefits in terms of eutrophication and acidification. Compost has also a potential for substituting commercial mineral fertilizers, with consequent benefits on eutrophication and human toxicity via soil and water. Potential impacts from compost could come from its content of heavy metals and their leachability to groundwater. Anyway, heavy metals could be limited by implementing proper waste management (e.g. separate collection).

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Bio-composting of organic solid wastes and its role in the rebuilding up of soil health

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Key words: composting, soil health, solid wastes

Abstract

This study introduced the compost use and its effects on crop yield and soil properties in two on-site field experiments, one for wheat-maize cropping system (1993-) and another for greenhouse vegetable cropping system(2002-) in Northern China.

Introduction

Organic solid wastes have been emerged as one of major environmental threats in China, with its annual huge output as including 2.4 billion t animal manure, 0.6 billion t crop residue and 0.1 billion t biosolid (Gao X.Z., 2002 □ China's Agriculture Yearbook, 1999-2006 □ Xu, 2003). Composting, as one of the effective treatment of organic solid wastes, had been practiced extensively in China, which can be ascended to the year of 1149 when Chen Fu recorded the composting method in his book "Chenfu Agricultural Book" and this helped the nation sustained the agriculture for 30 centuries. But the use of compost decreased sharply in last three decades with the development of conventional farming and only recently the treatment of those organic wastes became a concern mostly because of the pollution on waterbodies from those agricultural activities.

Numerous studies were undertaken in the world to understand the effects of compost use on soil properties and the growth of plants. Beside the benefits on the soil fertility, soil biodiversity and product quality, the environmental risks from compost, as the contamination from heavy metals, organic pollutants were also given studied in recent years (Fuchs, et.al.,2004; Brandli, 2005;).

Materials and methods

The experiments located in Quzhou County, Hebei Province, P.R.China. Six treatments were set for wheat-maize cropping trial (since 1993), as bio-compost 15 t/ha, traditional compost 15 t/ha, bio-compost 7.5 t /ha, traditional compost 7.5 t /ha, conventional fertilization and no fertilization. Each treatment was replicated 3 times and the area per plot was 10.5m×3m. The vegetable experiment was conducted in three side-by-side greenhouses (since 2002) with different management patterns: organic (ORG), Integrated(INT) and conventional(CON). The land occupation area of each greenhouse is 0.04hm². Soil physical, chemical and biological properties, crop yield and agro-inputs were recorded or analyzed.

Results

1. Compost use and crop yield

There were significant differences of wheat yield between 6 treatments after 10 years field trial (Fig.2, left). Both bio-compost (as EM compost, with inoculant in the beginning of composting) and traditional compost (without any inoculants) treatments gained compatible yield compared with the conventional CK. The higher compost application rate was applied, the higher wheat yield was reached. The yield differences between bio-compost and traditional compost were low, but stable.

The organic tomato production in the greenhouse also gained compatible yield after 4 years' trial. The higher use (60 t/ha) of compost in organic greenhouse justified it when compared with the minor use (10 t/ha) of compost in conventional greenhouse and half rate (30 t/ha) of the integrated greenhouse.

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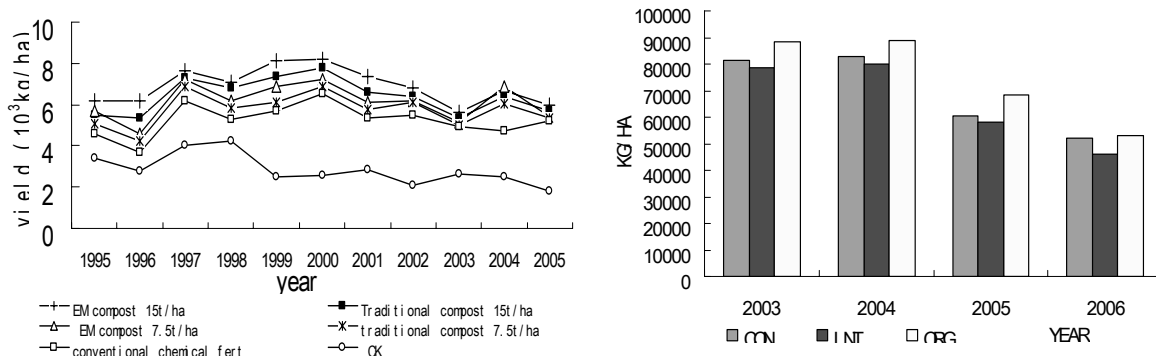


Fig. 1 Crop yield changes in two field trials: wheat (left) and tomato (right).

2. Compost use and soil properties

The effects of compost use on soil properties, as soil nutrients, soil organic matter and soil biological indicators, in those two field trials were similar. Compost amendments improved the soil organic matter and soil nutrients, both total and available nutrients after certain years. And the soil major biological indicators, such as soil earthworm and nematode density were significant higher in compost field than those in conventional fields.

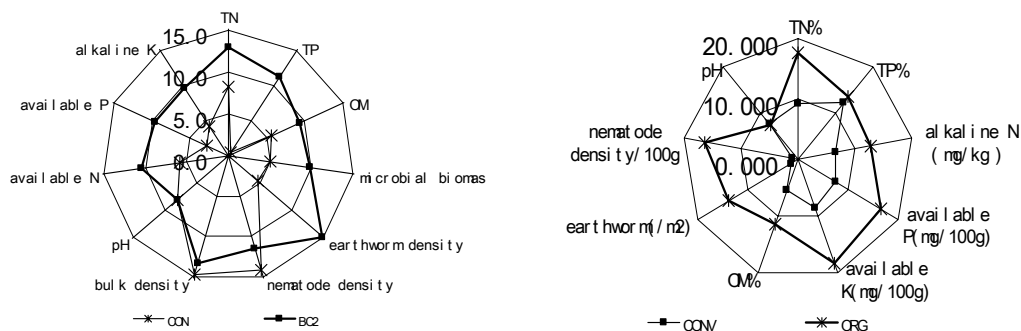


Fig. 2 Soil properties in different cropping systems: wheat-maize cropping system (left) and greenhouse vegetable cropping system (right).

Discussion and Conclusions

Compost use in both grain and vegetable growing systems revealed that the soil physical, chemical and biological properties were improved and crop yield could be compatible with those conventional systems. The C and N cycle and soil biodiversity need to be further clarified in a long-term view.

Acknowledgments.

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Session P1:

Needs and wishes of practitioners and authorities.

Waste policy at a crossroad: how to balance contradicting factors- extreme material recycling, boom in energy use and the fear of pollutants

Hans-Peter Fahrni¹

Key words: Compost and digestate, energy production, pollutants, waste management

Abstract

The increasing costs for fossil fuels and the planned higher payments for electric power produced with renewable energy have increased the demand for biogenic waste. The anaerobic digestion of suitable wastes competes with traditional composting and eventually with the incineration of waste in municipal waste incinerators. In parallel, the use of compost and digestate has positive effects to plants. So the waste management policy has to optimize the future treatment of biogenic waste, taking into account the energy production, the use for soil improvement and also the quality of digestate and compost. The costs for the separate collection of biogenic waste and the treatment costs have to be considered also. Even if in most samples heavy metals and organic pollutants are only present in low concentrations if not just traces, the quality of input materials has to be controlled. The policy for environmental protection which includes measures to reduce the background pollution, especially by organic pollutants, has to be continued.

The reasons behind the two research projects and today's situation

In the years 2002 and 2003, the Swiss government had to take a decision about the future use of sewage sludge as fertilizer in agriculture. At that time, all players in the field of agriculture were very nervous because of the mad cow's disease (bovine spongiform encephalopathy). In a short period of time, many long term users of sewage sludge lost their confidence in the quality the product, especially after first chemical analysis showed the presence of bioactive organic compounds as hormone active substances, antibiotics or other medicaments in the sludge. Big retailers such as MIGROS and COOP requested their suppliers to stop the use of sewage sludge. As a consequence, the use of sewage sludge in agriculture dropped drastically, even before any restrictive regulation was in force. As a matter of urgency, the federal office for the environment had to find emergency solutions for the elimination of sewage sludge. Looking beyond the immediate needs and possible solutions, the federal office decided to start a broad research project about compost.

One of the thoughts behind that research project was the concern that in the aftermath of the issues with sewage sludge the quality of compost could also be put into question. Already in 2002, about 750'00 tons of biogenic waste were collected separately and treated to compost or - at a lesser range - to digestate. Most of the produced compost was used in agriculture. If this use would have been reduced because of doubts about the quality of compost, Switzerland would have needed additional capacities for the elimination of 750'000 tons of biogenic waste.

Fortunately, the results of the two research projects show that the composts produced in Switzerland are of rather good quality, though further improvement is needed. The research projects also clearly proves the positive effects of the use of compost for the prevention of plant disease in agriculture and horticulture. Hence, one could conclude that all is fine: the future use of compost seems not to be put into question and no additional incineration capacity is needed.

But new problems are showing up. It seems that there is not too much biogenic waste but rather a shortage of it. We notice an increasing competition between different interest groups for the same biogenic waste. With the price of one barrel of crude oil having risen from 30 dollars to more than 90 dollars, the search for energy sources has intensified and biogenic waste is more and more perceived as something valuable which may be used for energy supply.

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Changing goals in the treatment of biogenic waste

During the last twenty years, the goal of the treatment of biogenic waste has changed at least four times.

1. A first concern in the history of composting was the fear of soil pollution by heavy metals contained in compost. Until 1986, Switzerland had no quality criteria for pollutants in compost. Considering that back then compost was produced from mixed urban solid waste, it was inevitable that such compost was polluted with high concentrations of metals such as copper, lead and even cadmium. Therefore, reducing the pollution caused by heavy metals was the first issue. Since 1990, the reduction of pollutants received more and more public attention. Hence, quality criteria for compost were developed and also to a large extent applied.
2. Between 1985 and 1990, the reduction of the over all amount of mixed urban solid waste was the most important goal. Composting - and to a lesser amount - anaerobic digestion - of separately collected biogenic waste, were encouraged to reduce the quantities of waste put into landfills and into incinerators. The recirculation of nutrients, mainly of phosphorous, as fertilizer into the soil, was a positive side effect of the separate collecting and recycling of biogenic waste.
3. In the years 1995 to 2000, reduction of cost was a main issue of waste management. The polluter-pays-principle in waste management was introduced in most municipalities of Switzerland. Citizens felt the pinch as they disposed of their waste and together with politicians they became very sensitive against increasing treatment prices. However, separate collection and treatment of biogenic waste was not abandoned but citizens were encouraged to compost the biogenic waste in their gardens or in the town district. In doing so, the compost was produced without increasing the cost of waste management.
4. Since the strong increase of crude oil prices and because of increased attention given to climate change, the production of energy from renewable sources became the new focus.

This frequent change in the goals of treatment of biogenic waste makes it difficult to follow a clear strategy (particularly with respect to communication). Furthermore, this may put investments in treatment plants at risk. Against this background we are currently defining a strategy which takes into account the following aspects

- Recirculation of nutrients as phosphorus to soil
- Improvement of soil quality
- Reduction of the load of inorganic and organic pollutants to soil
- Use of energy content in biogenic waste
- Costs for separate collection and treatment of biogenic waste
- Investments in existing plants and collections systems

Some remarks to the different goals

Concerning the use of nutrients, phosphorus is amongst the elements which are absolutely not replaceable for growth of plants and animals. The reserves of phosphorus are clearly limited. Therefore, in the long term, agricultural production is reliant on a sustainable use of phosphorus. Losses of phosphorus by mixing it with contaminants from other wastes in landfills should be avoided. Nevertheless, among the different biogenic wastes are several fractions with a much higher phosphorus concentration than the vegetable wastes. Especially bones from slaughter houses are high in phosphorus. For this reason, bone meal was used as fertilizer. But as a consequence of the mad cow disease the direct use is no longer allowed. When bones are incinerated, the resulting ash contains 50% of calcium phosphate. Bone and meat meal should be burnt separately so that the resulting ash can be used as fertilizer. Burning bone and meat meal in cement kilns and in coal fired power plants means losing the phosphorus in these fractions because it cannot be recuperated at reasonable costs - neither from concrete nor from the coal ash. When sewage sludge is burnt separately or in combination with bone meal, the resulting ash will show a high phosphorus concentration. It can be used as fertilizer without problems since it has basically no organic pollutants. There are also ideas to stock the ash from sewage sludge incineration in dedicated landfills for future use.

Soil improvement by the use of good quality compost remains certainly an important goal. The detected positive effects of compost against plant diseases make this aspect even more important.

For that reason, a sufficient amount of compost of good quality should be available in future for the applications where compost can not be replaced.

The enormous progress in analytical chemistry makes it possible, to detect concentration of pollutants in the range of some picograms (10^{-12} g) per kilogram. Hence, the good old idea to set a limit value in the range of the detection limit is no longer a good one. A little technical progress will boost the sensitivity of the analytical system by a factor of hundred and we will find detectable amounts of pollutant in every sample which is analysed. This means, that the evaluation of toxicity and the determination of the ecological significance of traces have to be made for much more substances than in the past.

To simplify matters, one could say that pollutants found in compost or digestate have two main categories of sources. The first are clearly isolated or point sources. At the origin could be the use of biogenic waste which is polluted by local applications of pesticides or other pollutants. If spoilt vegetables and fruits which were treated with pesticides are composted, it will not be astonishing to find these pesticides also in the resulting compost or digestate. To reduce this pollution from defined sources, contaminated wastes should not be put into treatment chains that are supposed to produce good products as fertilizer. Heavily contaminated raw material should go to a treatment where the resulting products are incinerated.

The second category of sources for contaminants in biogenic waste is much more complex, it is the whole range of diffuse sources which exist in our society. In most cases the pollutants are transported through the atmosphere to the plants. Combustion processes produce poly aromatic hydrocarbons, and the uncontrolled burning of waste - which unfortunately is a persisting bad habit in many rural regions, produces chlorinated dioxins and furans and also PCB. The processes of composting and anaerobic digestion both reduce the quantity of the remaining material. Consequently, the final product contains higher concentrations of the not degradable pollutants in comparison with the original raw material. In some cases, especially for PAH, the additional charge added to the soil through compost or digestate may be important in comparison to other loads from manure or fertilizers.

The importance of diffuse sources is a clear incidence for the necessity to make further progress in the field of air pollution control. The actual sophisticated flue gas cleaning systems in waste incinerators reduced the emissions of dioxins and furans by several orders of magnitude. Concerning the PAH, it will be important to reduce the emissions of motor vehicles, especially those of diesel-engines. Concerning other chemical pollutants, the new EU Regulation on chemicals and their safe use may bring a more restrictive use of some of the most problematic substances.

Looking at the caloric value of biogenic wastes, wood is certainly a major factor for any increase in the production of renewable energy. In the last years, about 400'000 metric tons of waste wood from demolition of buildings was exported annually. It was used either for production of boards and panels made of wood chips or it was burnt in foreign power plants. If the wood does not contain too much pollutants, such as heavy metals from varnishes and paints, both uses are acceptable from an ecological point of view. But the interesting question is why this waste wood is exported. As a matter of fact, there are no very strict quality criteria for the production of boards and panels from wood chips, and the use of waste wood is cheaper than the use of new wood. Furthermore, the combustion in power plants is financially interesting because electrical energy yields higher prices, when wood is used instead of coal. This is an example of the problems that the regulator faces, if he would like to assure that this waste wood is utilized in Switzerland for energy production. If there are no ecological reasons for an export ban, higher subsidies for the renewable energy would have to be paid than what foreign plants receive or protectionist rules stipulated which will increase costs for Swiss waste producers.

Some conclusions for the legislator

The first priority of waste management policy will be to avoid damage to public health and to common goods as ambient air, water or soils. Therefore, the emissions of treatment plants have to respect the existing norms. In some cases, these requirements will have to be complemented. For example: because methane has a high greenhouse potential, the digestion plants should leak as little gas as possible. In addition, quality criteria for the products of waste treatment which are applied on soil are needed, independent from the treatment process of biogenic waste. This is also true for products which result from the co-digestion of manure and biogenic wastes.

For obvious reasons stranded investments should be avoided. Hence, authorities and private organisations are well advised to carefully follow the statistics about treatment capacity and amounts of treated waste. And they should also improve the quality of data about the potentially available quantities of different biogenic wastes.

In a society which tends to foster a free market also in the field of waste treatment, it is rather difficult if not impossible to allocate a certain waste to one special treatment system, unless there would be clear ecological reasons to do so or if the additional costs were insignificant compared to the ecological advantages. Therefore, if waste wood can be used in a power plant or in a municipal solid waste incinerator, we will probably rather allow both ways and not forbid to burn some pieces of wood in an MSWI. But of course further increase in the energy efficiency of incinerators remains a continuous challenge.

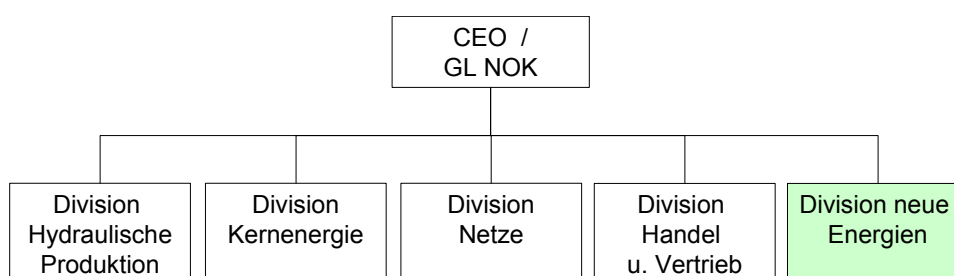
One example where a specific allocation of waste seems probable is the treatment of substantial volumes of wet biogenic waste from food processing or from canteen and restaurant kitchens. This waste is really suitable for anaerobic digestion and has a low calorific value in incinerators. Hence, burning it in waste incineration plants would certainly be less efficient than anaerobic digestion.

The energy industry and organic waste materials

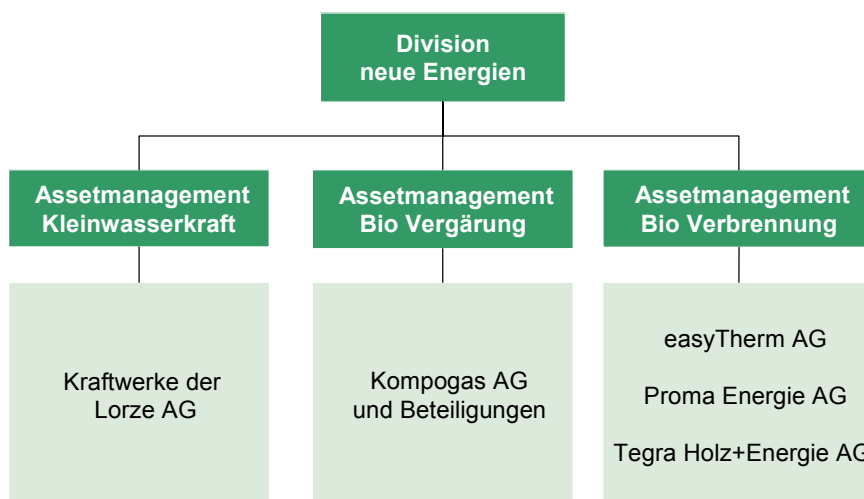
Valentin Gerig ¹

Introduction

At the beginning of 2006, Nordostschweizerische Kraftwerke AG (NOK) devised its strategy for the field of new renewable energies (new energies). By 2030, NOK aims to extract 1,800 GWh of electrical energy from renewable energy sources. Within the spectrum of new energies, NOK is focusing on generation of electrical energy from small-scale hydropower (output of up to 10 MW) and biomass. At the time of devising this strategy, NOK's focus with regard to generation of electrical energy had until then been on the construction and operation of large-scale hydropower plants and nuclear power plants, so NOK lacked the know-how required for new energies, and primarily for the generation of electrical energy from biomass. Thus, in February 2006, NOK took holdings in various companies which had suitable competence and expertise in the relevant technologies and purchasing markets. Activities within NOK which pertain to new energies are encompassed by the New Energies Division.



Today, NOK is involved in the generation of biogas and electrical energy from the fermentation of green waste and kitchen waste via the Kompogas Group, and in wood-based generation of heat and electricity (e.g. from waste wood) with Proma Energie AG, Opfikon, and Tegra Holz + Energie AG, Domat/Ems. NOK's New Energies Division is subdivided into three business units:



The actual projects for generation of new energies are not realised by NOK, but by the specialised companies which collectively constitute the operational basis of the New Energies Division.

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Electrical energy and heat from waste wood

Today, Tegra Holz + Energie AG, in which NOK has a 20% holding, operates a heating plant in which it generates a thermal output of 5.5 MW from waste wood, as well as a wood-fired power plant with 38 MW thermal output and 11 MW electrical output, which is fuelled with young timber. A third power plant unit, with a 38 MW combustion capacity, is under construction. As of 2009, Tegra will use these plants to supply steam and heat to a nearby chemicals factory and a sawmill, and to feed around 80 GWh of electrical energy into the grid.

In Kleindöttingen, NOK operates another wood-fired power plant with its subsidiary Proma Energie AG. Here also, heat and electrical energy are generated from waste wood. Tegra and Proma are planning a number of additional power plants.

With the improved subsidy conditions for new energies, as passed in Parliament, organic waste materials such as waste wood are becoming a coveted resource. While this also inherently applies for young timber, NOK and its holdings are primarily focusing here on cleared wood, branchwood and bark, in other words: parts of trees which, in the past, were often left lying in the forest.

The waste wood market is of great interest. However, today a large portion of the approximately 750,000 - 850,000 tons of waste wood in Switzerland still goes to Italy for material recycling, or into wood-fired power plants situated there, or also into refuse incineration plants in Switzerland. Here, the subsidisation scheme for new energies may somewhat improve the commercial conditions for utilisation of waste wood in Swiss wood-fired cogeneration plants.

Electrical energy and fuel from green waste

In 2006, NOK took holdings in the Kompogas Group, which builds biogas plants for anaerobic dry fermentation of green waste, and which operates nine plants in Switzerland. In the coming years alone, Kompogas intends to build around 15 new plants in Switzerland. Meanwhile, the sustainable availability of biomass is also emerging here as a key to success. For this reason, Kompogas has sought to work together with various composting companies, and has taken holdings in several such companies. Two years ago, Kompogas processed around 100,000 tons of green waste. Today, this has risen to over 200,000 tons. Around 10 GWh of electrical energy from the biogas produced is fed into the grid, and the rest is processed to natural gas quality and sold as biogas fuel, either at self-owned fuelling stations, or via natural gas companies.

Large volumes of fermented product also arise from the processed green waste. This is compressed and sieved, and in many cases, given to local residents free of charge, or used in agriculture or nurseries at a low price. Due to its holdings in composting companies, Kompogas has also acquired know-how in the further processing of the fermented product to make high-quality compost, so the fermented product which is made can be channelled into profitable utilisation in the medium term.

Size entails responsibility

Due to its holdings in the Kompogas Group, NOK has become one of the largest producers of fermented product in Switzerland. Even though NOK sees organic waste materials primarily as raw materials for the production of electrical energy, in our operation of biomass plants we are much more involved in the market for purchasing and selling of by-products than in the electricity market. In this respect, from an integrative point of view, new questions must arise for the companies in the electricity industry, for instance with regard to the following:

- origin of the biomass (foodstuffs or waste, cultivation of energy crops crowding out land which could be cultivated for foodstuffs production, or recultivation of fallow land, environmental performance evaluations, etc.)
- thinking in terms of material cycles (refining of fermented product into quality soil and compost, as well as returning it to nature, instead of a one-sided focus on the production of electrical energy or fuels from fermentation)
- new cooperation partners for utilisation of by-products (e.g. cooperation with farmers and horticultural companies for utilisation of fermented product / compost)

If the electricity companies which wish to be involved in the field of electricity production from biomass (and of those, the large ones in particular) do not take on these responsibilities, they are exposing themselves and their investments to considerable risk with regard to fermentation, but primarily the composting industry: in Switzerland in recent years, competition has emerged between refuse incineration plant operators, and operators of industrially operated and agricultural biogas plants. If the biogas plant operators do not manage to ensure a sustainable high compost quality, significant advantages over the incineration of biomass in refuse incineration plants will be lost, and even official bodies could retract their support for the fermentation of green waste and kitchen waste.

Indeed, Switzerland's large electricity companies are repeatedly asked whether their involvement in the field of new energies is a fig leaf for the construction of new nuclear power plants. However, this must be ruled out, on the basis of size alone, and often also by the composition of the stockholders (public sector). The large electricity companies in particular must not pursue the new energy products solely for reasons of media presence, but must also accept obligations based on strict ecological, economical, social and energy-industry-related criteria, in line with an integrative approach.

Thus, NOK is making an honest effort to measure its investment projects in the field of new energies on the basis of requirements which sometimes go beyond the legal regulations, and the here and now. With our investments, it is our responsibility to already anticipate foreseeable future issues today (e.g. 'grey' CO₂ emissions from new energies, humus atrophy, water consumption in the cultivation of energy crops, further reorganisation and development of structure in industries such as sawmilling, forestry and agriculture). In so doing, it may be necessary to accept a reduction in projects' profitability.

Session P2:

Process management and product quality

From substrate to application: microbes do the job

Heribert Insam¹, Ingrid Franke-Whittle¹, Sabine Mayrhofer¹, Armin Hansel², Brigitte Knapp¹

Key words: microbial communities, compost, microarray, DGGE, COMPOCHIP, wood ash, VOC

Abstract

Composting and anaerobic digestion are often viewed as chemical processes and engineers tend to forget that it is microorganisms that do the job. This paper shows a few examples how - at different levels - microbes affect the process of composting and are affected when composts are applied to soils.

First it is shown that even after long-time application composts of different origin (manure, sewage sludge, organic waste, green waste) have little effect on bulk soil properties, but to a considerable extent change functional and structural properties of the soil microbiota. Secondly, we show how the combination of two waste streams – biowaste and wood ash - may benefit the resulting compost quality. And thirdly it is shown how a novel molecular biological tool (the COMPOCHIP microarray) may be used for monitoring compost production and use.

Introduction

Process management starts from the selection of the input materials, be it for composting, or be it for anaerobic digestion. Of course, lignocellulosic materials will primarily be treated aerobically, while other materials containing less structural compounds would ideally be treated by anaerobic digestion resulting in biogas production. On the other hand, also combinations of anaerobic and aerobic treatment are quite common, for example the composting of anaerobically digested sewage sludge. Another simple example of the combination of sequential anaerobic and aerobic treatment is rumen digestion, which is followed by aerobic composting of manure.

During the digestion process, be it aerobic or anaerobic, certain parameters have proven to be suitable process indicators. These indicators may also be used for process regulation: heat production potential, temperature, acidity, electrical conductivity, CO₂ production or O₂ consumption. Several papers in this issue address these parameters (ref.). Microbes, however, have so far received little attention, despite their vital role in decomposition processes.

In this paper we address several issues that we have been studying in our laboratory. We start from the effect of compost substrate on the soil chemistry and microbiology, continue with the option of combining different waste streams (organic wastes and wood ashes) and finally the introduction of a novel tool for process monitoring, a microarray targeted at the microbiota of composts.

Materials and methods

From input quality to product performance

In a long-term experiment we studied the effect of four different kinds of composts on crop yield and soil microbiological properties. The treatments were

- (1) Soil without fertilization (control),
- (2) Compost amendment corresponding to 175 Kg N ha⁻¹
 - (2a) urban organic waste compost from source-separate collection, (OWC);
 - (2b) green waste compost (GC);
 - (2c) cattle manure compost (MC)
 - (2d) sewage sludge compost, (SSC)
- (3) Composts+N corresponding to 175 Kg N ha⁻¹ from compost plus 80 Kg mineral N ha⁻¹ (NH₄NO₃) (OWC+80; GC+80; MC+80, SSC+80).
- (4) Mineral fertilisation treatments corresponding to: 40, 80 and 120 kg N (NH₄NO₃) ha⁻¹.

We investigated the effect of these treatments on soil organic and microbial C pools (Ros et al., 2005), and on the soil microbiota, both on a structural (16S rDNA - genomic) and functional (community level

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physiological profiling, CLPP) level (Ros et al., 2005, Innerebner et al., 2006). Further, on the level of metabolomics we studied the emission of volatile organic compounds (VOCs).

Admixture of wood ash to organic wastes

A classical method to lower acidity of composts is the amendment of lime, a feature that we also attribute to wood ash. Its nutrient and micronutrient contents on the one side, and its contents of pollutants like heavy metals on the other side, are challenging for producing intelligent fertilizers or soil conditioners.

In a series of experiments we used wood ash from wood incineration plants. These are increasingly common in Austria and in many other countries. So far, plant operators had to depose of the ashes at high costs, also because of legal constraints concerning the use of wood ashes as fertilizer or as compost amendment. After screening the literature for average pollutant contents we realized that most of the bottom ashes have heavy metal and xenobiotic contents low enough so as to not be detrimental to the quality of composts made from organic wastes (Stockinger et al., 2005).

Three composts were produced from source separated organic waste with or without an amendment of 8% or 16% wood ash. The maturation of the composts was monitored by measuring C/N-ratio, microbial biomass, microbial activity and also through plant growth tests. The mature compost was tested for electrical conductivity and pH. The same parameters were used to analyse the soils of an *in situ* recultivation experiment at the skiing area Mutterer Alm near Innsbruck, Austria. The three mature composts were compared to a mineral and organic fertilizer treatment.

Microarrays as a microbiological monitoring tool for hygiene and maturity

With our COMPOCHIP microarray (Franke-Whittle, et al., 2005) we are able to determine the presence or absence of many different microbial genera and species. Total microbial DNA is extracted from a compost sample, labeled and hybridised with the probes attached to the microarray. The array includes probes for many plant, animal and human pathogens, plant growth promoting organisms, general 'degraders' found in composting processes and typical soil bacteria.

In a preliminary experiment we investigated three maturity stages (2, 8 and 16 weeks) of a green waste compost, a manure compost and a compost made from anaerobic digestate by a prototype of the COMPOCHIP microarray.

Results and discussion

From input quality to product performance

The substrates all met the basic requirements for compost of the A-level according to Austrian legislation. The heavy metal contents of the SSC, however, were about 2-3 times higher than those of the other three composts (Ros et al., 2006).

While there were no differences among OWC, GC and MC concerning soil organic carbon, with SSC more carbon was retained in the soils (Table 2). The elevated metabolic quotient in these soils suggests that the SSC contained inhibitory substances, potentially heavy metals. However, a more balanced nutrient composition offset this problem since no inhibition of plant growth was observed (Fig. 1).

Table 1. Chemical properties of the composts (on a dry weight basis, mean \pm SD, n=4) (Data from Ros et al., 2006)

Composts	Urban organic wastes compost	Green compost	Manure compost	Sewage sludge compost
Organic matter (g kg ⁻¹)	330(42)	350(29)	270(35)	470(38)
Total nitrogen (g kg ⁻¹)	12(1.8)	16(0.6)	13(0.7)	22(2.0)
C/N	16	13	10	12
P ₂ O ₅ (g kg ⁻¹)	27(1.3)	14(1.0)	12(0.8)	19(1.6)
K ₂ O ₅ (g kg ⁻¹)	6(0.5)	13(0.5)	13(0.2)	32(0.9)
Cu (mg kg ⁻¹)	70(1.5)	38(1.3)	41(1.4)	168(1.0)
Zn (mg kg ⁻¹)	277(4.5)	163(3.8)	213(2.8)	630(4.3)
Ni (mg kg ⁻¹)	21(1.3)	22(1.0)	19(0.5)	36(0.8)
Cr (mg kg ⁻¹)	32(1.2)	28(0.6)	15(0.5)	40(1.3)
Pb (mg kg ⁻¹)	75(2.8)	28(2.2)	13(1.8)	70(2.4)
Cd (mg kg ⁻¹)	0.56(0.02)	0.34(0.01)	0.20(0.01)	0.89(0.01)
Hg (mg kg ⁻¹)	0.24(0.01)	0.15(0.009)	0.07(0.009)	0.85(0.1)

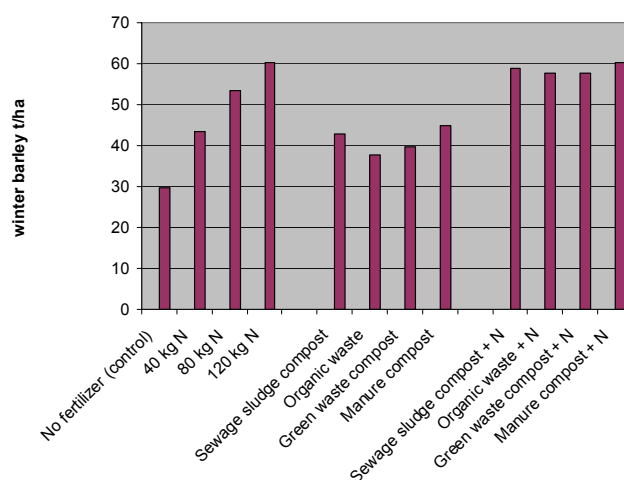


Fig. 1. Average crop yield of the differently treated plots

Table 2. Organic C (C_{org}), total N, C/N ratio, microbial biomass, basal respiration and metabolic quotient of control soils, and soils treated with mineral fertilizers and/or composts (Ros et al., 2005).

Treatment	C _{org} (g kg ⁻¹)	Total N (g kg ⁻¹)	C/N	C _{mic} (μg g ⁻¹ soil)	Basal respiration (μg CO ₂ -C g ⁻¹ soil h ⁻¹)	qCO ₂ (mg CO ₂ -C g ⁻¹ C _{mic} h ⁻¹)
Control	11.8 (0.5)a ^a	1.48 (0.10)a	8.0 (0.7)ab	123.9(7.8)a	0.53(0.09)b ^a	4.3(1.0)b
80	11.4 (0.5)a	1.40 (0.13)a	8.1 (0.8)abc	128.6 (8.2)abc	0.48 (0.13)a	3.7 (1.3)ab
OWC	13.4 (0.6)bcd	1.68 (0.05)b	8.0 (0.5)abc	134.0(7.1)bcd	0.54(0.06)b	4.1(0.3)b
GC	14.2 (1.4)cd	1.60 (0.15)ab	8.9 (0.6)bc	136.3(12.9)cd	0.57(0.08)b	4.2(0.2)b
MC	12.6 (0.6)ab	1.53 (0.10)ab	8.4 (0.3)abc	127.9(7.0)abc	0.53(0.04)b	4.1(0.3)b
SSC	14.3 (1.2)d	1.58 (0.10)ab	9.1 (0.4)c	129.7(8.1)abc	0.76(0.07)d	5.9(0.5)d
OWC+80	12.3 (1.1)ab	1.65 (0.06)ab	7.4 (0.4)a	147.2(7.2)e	0.57(0.08)bc	3.9(0.4)b
GC+80	13.0 (0.8)abc	1.63 (0.05)ab	8.0 (0.3)ab	141.2(4.2)de	0.56(0.10)b	4.0(0.7)b
MC+80	13.0 (0.6)abc	1.58 (0.10)ab	8.1 (0.8)abc	136.7(6.0)cd	0.41(0.09)a	3.0(0.8)a
SSC+80	14.2 (0.9)cd	1.60 (0.08)ab	8.6 (0.7)abc	135.8(8.7)bcd	0.67(0.08)cd	4.9(0.5) c

^a Numbers in parenthesis indicate standard deviation, n=4. Means followed by the same letter are not significantly different according to Tukey's (p<0.05) between different treatments.

We found that the composts left traces on the microbiological level in the soil that are not to be attributed to direct (inoculation) effects, but to a change in physico-chemical soil properties inferred by the composts. On the bacterial community level, function (CLPP), and structure (PCR-DGGE) based approaches were used. Both CLPP and DGGE separated all three major types of treatments (mineral fertilisation, composts only, composts plus mineral fertiliser) from each other. Furthermore, even differences between the various types of composts were detectable, in particular with CLPP and – using specific primers for ammonia oxidising bacteria also with DGGE (Ros *et al.*, 2005) and with a cloning approach (Innerebner *et al.*, 2006) (Fig. 2).

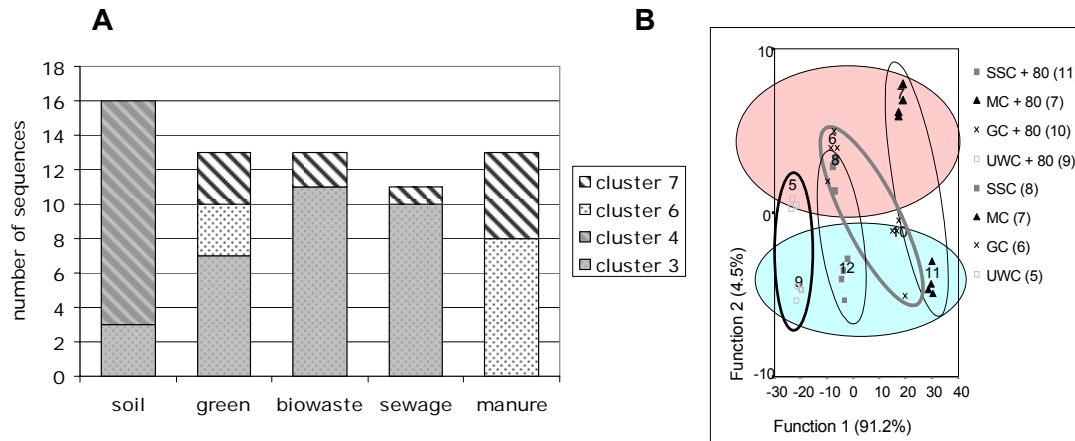


Fig. 2. [A] Number of clones of ammonia oxidising bacteria of various groups (Innerebner *et al.*, 2006) and [B] CLPPs were used to discriminate among microbial communities of differently treated soils (Ros *et al.* 2005).

In an ongoing project we are attempting to reveal if the composts also leave an effect at the level of volatile organic compounds (VOC) that might originate from the composts or from metabolic products liberated through action of the (compost-altered) microflora. Results suggest that the different composts do emit different VOCs (Fig. 3). If these different emission patterns will persist after application to the soils will be investigated in an ongoing study. Preliminary results indicate that genetic profiles are more sensitive than VOC emission patterns, still, the detection of VOCs from soils and composts may be regarded as an important step from genomics to metabolomics.

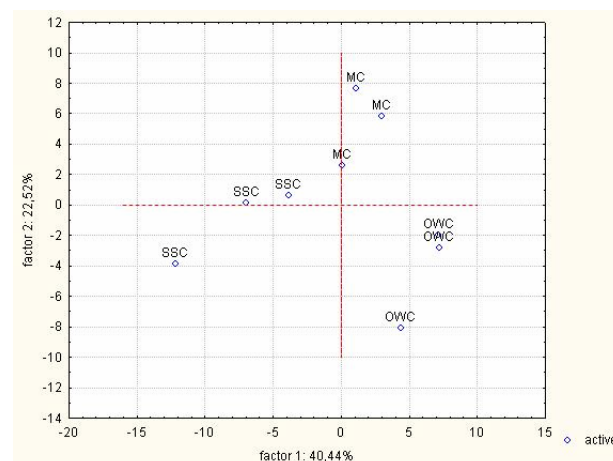


Fig. 3 Principal component analysis of VOC patterns of sewage sludge compost (SSC), manure compost (MC) and organic waste compost (OWC). VOC patterns clearly separate the composts from each other.

Admixture of wood ash

All composts produced with 8 or even 16% wood ash amendment fulfilled the requirement of the Austrian Compost Ordinance (Compost Quality A or even A+). In the field experiment, the highest soil microbial biomass was found for the compost that had received 8% ash (Fig. 3).

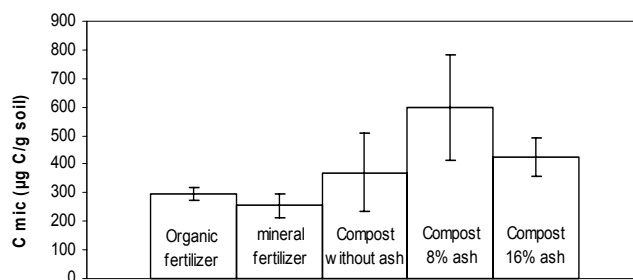


Fig. 3. Microbial biomass in soils of a reclamation experiment at Mutterer Alm, Austria, where composts with different amounts of wood ash were compared to organic and mineral fertilizers (from: Kuba et al., in press)

Best plant growth was obtained from the compost amended plots, even when compared to organic fertilizers. Respiration measurements indicate a better performance of composts amended with 8 or 16% ash as compared to compost that did not contain ash.

Table 3. Comparison of plant growth in the field experiment Mutterer Alm: total soil plant cover (% of the area), and coverage by grasses and legumes, as well as overall impression (1-9, 1 = very good, 9 = very poor). Dissimilar letters in a row indicate statistically significant differences among the treatments (means \pm SD, Tukey B test) (from Kuba et al., in press)

	<i>K0</i>	<i>K8</i>	<i>K16</i>	<i>AB</i>	<i>MD</i>
<i>Total plant cover [%]</i>	70.5(\pm 4.2)a	71.5(\pm 5.0)a	65.0(\pm 3.1)a	52.5(\pm 9.5)b	38.0(\pm 2.7)c
<i>Grass cover [%]</i>	39.0(\pm 2.6)a	40.0(\pm 5.1)a	37.0(\pm 2.0)a	31.8(\pm 7.2)b	26.0(\pm 2.6)b
<i>Legume cover [%]</i>	29.0(\pm 2.3)a	30(\pm 2.9)a	26.8(\pm 2.1)a	19.3(\pm 2.6)b	10.5(\pm 5.0c)
<i>Overall impression [1-9]</i>	2.4(\pm 0.7)a	2.3(\pm 0.9)a	2.9(\pm 0.6)a	5.1(\pm 1.4)b	7.1(\pm 0.41)c

Microarrays as a microbiological monitoring tool for hygiene and maturity

Little is known about the relationship between compost quality and microbial colonisation, albeit it is microorganisms that do the job of decomposition. A correlation between chemical and biological properties of composts has been found by several scientists using humus fractionation methods, thermogravimetry and near infrared spectroscopy, respectively. It is still not known if it is the microflora indigenous to the composts that confer plant disease suppressiveness, or if it is the triggering of a specific soil-based community by the composts that confers such effects. This cause-effect relationship may further depend on the type of suppression we are looking at, be it specific or general resistance against soil-borne disease, or induced resistance against foliar pathogens

There are numerous examples of composts that are able to protect different types of plants against certain parasites (Fuchs et al., 2004). It is challenging to the researcher that not all composts have the ability to efficiently inhibit plant diseases. The strong variability in the observed effects amongst different samples is certainly the greatest obstacle to the large-scale use of composts with the specific aim of protecting plants. The production of composts with defined, constant qualities is an indispensable requirement for satisfying the expectations of those using compost in this way.

Our results showed that the microbial community composition was different among the three compost types made from green waste (C-green), anaerobically digested sludge (C-andig) and manure (C-manure mix) composts (Fig. 4). Along axis 1, the green waste compost after two weeks was most different to the manure and anaerobic digestate compost. Upon maturation of the composts however, the microbial community composition was found to be more similar.

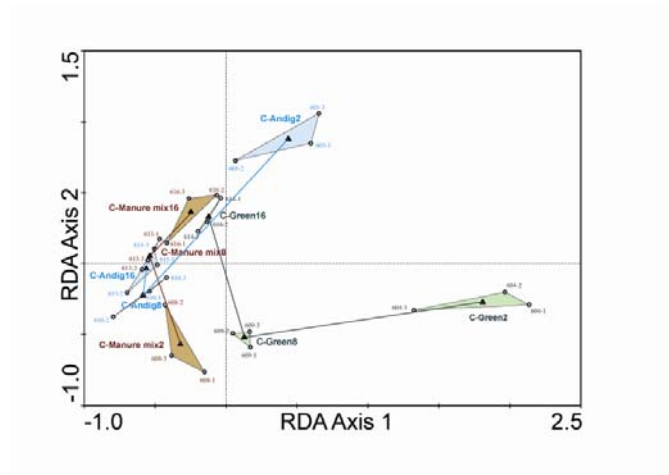


Fig. 4. Discriminant analysis plot of COMPOCHIP microarray data of three different composts with ages of 2, 8, and 16 weeks.

Conclusions

At the level of compost production and application microbial communities can serve as indicators at the genomic and metabolic level. A more intricate knowledge on microbial community structure and function may eventually lead to a better process regulation.

Acknowledgments

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Airflow pressure drop evaluation in forced aeration composting

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Key words: Composting, forced aeration, airflow resistance, waste management, swine manure

Abstract

This study intends to help the design of an aeration system for a forced aeration composting process, particularly on the estimate of the pressure drop through the pile, key parameter for an adequate blower selection. The substrate head loss results of a model based on flow through porous media theory, as Ergun equation, and simple measurements carried out to the substrate (total bulk density, dry matter content, organic matter content and particle size). It would be possible to avoid a pilot scale test, to collect data, for each different substrate to compost. The experiments were performed on a real scale pilot with swine manure substrate and the objectives were to measure the vertical airflow resistance of the waste pile and to evaluate the model by comparing the theoretical and the experimental values of pressure drop.

Introduction

Aeration is a key parameter in composting. Therefore the ventilation system is an important element on a composting facility design. Composting with a forced aeration system, in this case, implies the use of a blower to inject air beneath the pile by means of a manifold, which delivers air uniformly to the waste pile.

The blower selection depends on two main variables: the volumetric air flow needed and the head loss of the system. The former aims to satisfy the microbes' respiration needs, optimal temperature and humidity. The latter refers to the air static pressure drop of the air flow throughout the total manifold system and through the waste pile.

The present study addresses the issue of pressure drop estimate on airflow through a substrate. The main purpose is to estimate the head loss on the composting pile based on simple measurements: total bulk density, dry matter content, organic matter content and particle size. The objectives were to measure the vertical airflow resistance of a substrate, to fit the experimental data to the airflow resistance model and to evaluate the model by comparing the theoretical and the experimental values of pressure drop.

The model considered on this study is based on the Ergun equation and Kozeny-Carman experiments, referred to in Bear (1972):

$$\frac{\Delta P}{h} = 150 \cdot \mu \cdot \frac{(1-\varepsilon)^2}{d^2 \cdot \varepsilon^3} \cdot v + 1,75 \cdot \rho \cdot \frac{(1-\varepsilon)}{d \cdot \varepsilon^3} \cdot v^2$$

The pressure loss (ΔP) per unit of pile heights (h) depends on two terms. The first term reflects the viscous forces influence, being a linear function of air flow velocity (v), which includes the fluid dynamic viscosity (μ), the medium particle size diameter (d) and the quantity of the medium free air space (ε). The second term, with the quadratic velocity term, introduces a non-linear behaviour, reflects the drag forces influence and includes the fluid density (ρ).

To obtain the pile head loss from the equation stated before, tests to the substrate must be performed in order to determine the particle size and the porous matrix free air space. The particle size diameter is obtained by means of a screening test. The free air space is estimated based on the work of Van Ginkel et. al. (1999):

$$\varepsilon = 1 - \rho_{bulk} \left(\frac{1-DM}{\rho_w} + \frac{DM \cdot OM}{\rho_{om}} + \frac{DM \cdot (1-OM)}{\rho_{ash}} \right)$$

Therefore, ε can be directly calculated, on a theoretical basis, from easily measured values of total bulk density (ρ_{bulk}), dry matter content (DM), organic matter content (OM) and knowing the densities of water, organic matter and ash (ρ_w , ρ_{om} , ρ_{ash}).

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Materials and methods

An experimental pilot was used to provide real data for the study and the experiments were performed on swine manure substrate. The pilot design consists of a turning windrow composting system with forced aeration. The aeration system has a blower which is connected to a set of ducts distributing the air underneath the windrow base. The air is forced through the pile and the pressure drop across the waste is measured with a U manometer (at different instances in time, with different levels of moisture content and bulk density). The air flow is measured with an anemometer, installed in the duct after the blower discharge.

Each instance of experimental data collection triggered a substrate screening test, a bulk density measuring test, dry matter and organic matter content determination.

Results

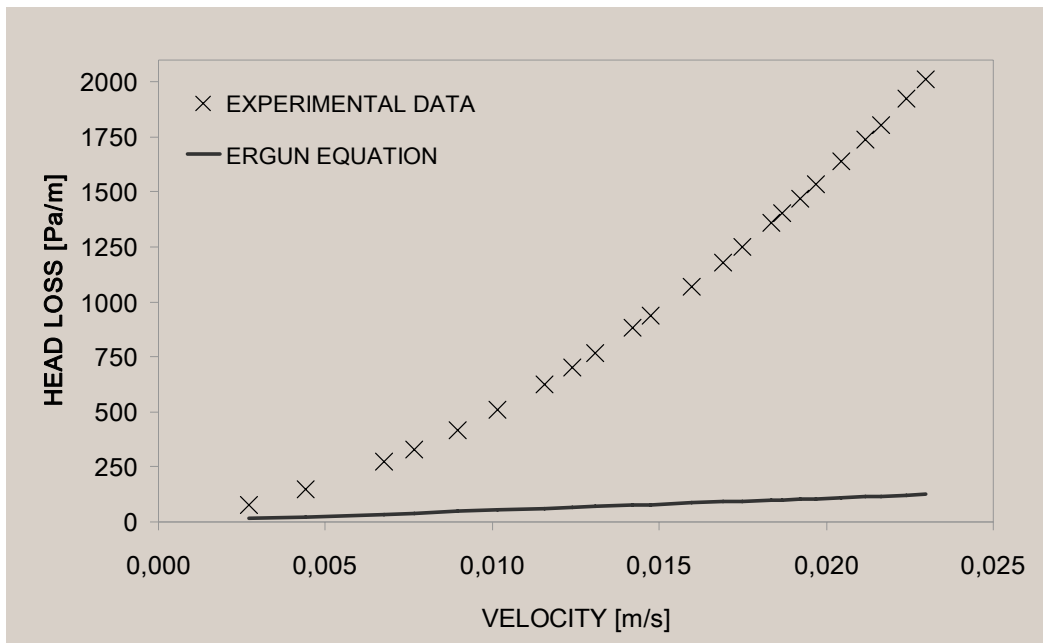


Figure 1: Behaviour of Velocity vs. Head loss for theoretical and experimental data.

Discussion and Conclusions

As shown on figure 1, the non-linear behaviour measured in reality is clearly more evident than the model predicts. Although the use of Ergun model appears applicable over a wide range of materials and flow rates, it is still a great issue the applicability of mathematical modelling to organic substrates and the gain accomplished in describing reality. Such a difference between theoretical and experimental results may also be explained by the choice of an experimental pilot scale to perform the reality data collection instead of the usual controlled laboratory experiments, which leads to an increase of disturbing factors to the process.

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Comparison of different anaerobic pre-treatment methods for biowaste with regard to potential of biogas production

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Key words: biowaste, percolation, elution, anaerobic digestion, biogas potential

Abstract

Treatment of separately collected biological waste is state of the art in Germany for almost 20 years. In 2004 in Germany about 12.4 million tons of biological wastes (from garden, households, parks, kitchens, small industries, food industry, agriculture) were treated.

There are two general treatment options for biowaste: composting and anaerobic digestion. In Germany approximately 90% of the biological waste is treated aerobic in about 825 composting plants and about 10% are treated anaerobic in round about 75 biogas plants. But the ratio between anaerobic and aerobic treatment changed over the last years due to many aspects (e.g. financial issues), so that the number of biogas plants is increasing more and more. [Wiemer et al., 2000]

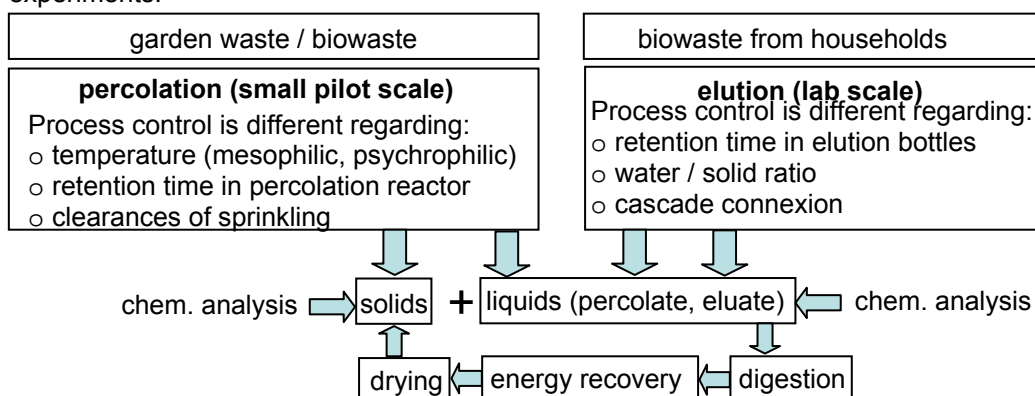
The focus in this paper is put on two types of wet pre-treatment of biowaste: percolation and elution. The investigations that are performed at the Institute of Waste Management (IAA) TU Dresden (Germany) aim at an optimal process design to increase the transport of readily biodegradable substances into the liquid phase and therewith to increase the biogas potential in liquid phase. The produced biogas can be used for energy recovery and is considered to meet the demand on energy for drying the solids after percolation or elution. The solids can be used for several kinds of further processing: e.g. for incineration in biomass power stations or for biofuel production as it is subject of a current project at IAA TU Dresden. In the following this paper represents first results with regard to influences of certain parameters on the substance transport into the liquid phase during percolation and elution of biowaste.

Introduction

Percolation is known as a treatment technology for organic waste and household waste for some years. [FNR, 2007] In Germany several plants exist and many investigations were done to find the best way of operation. Besides percolation another kind of wet pre-treatment can be taken into consideration to enrich the liquid phase with readily biodegradable substances for digestion: elution processes. Both processes are investigated at IAA TU Dresden. All experiments aim at a detailed survey on different influences on the process of dissolving of substances into liquid phase and therewith on the biogas potential.

Experimental setup

The following diagram represents the different experimental setups for elution and percolation experiments:



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First percolation experiments were performed in small pilot scale and first elution experiments in lab scale experiments. For the percolation 10 kg of biowaste (either separated biowaste from households or garden waste) were put into four reactors with each a useable volume of 80l. The four reactors are operated different with regard to retention time in the reactor, clearances between sprinkling, temperature and / or input material. Parallel to the percolation experiments the possibility of elution was investigated with different duration of elution, different water / biowaste ratios and with different types of cascade connexion.

The liquid and solid samples from percolation and elution were analysed for different parameters like COD, Cl, S, DOC, heavy metals etc. to collect data about the transport of substances into liquid phase.

Results and conclusion

Due to the shortness of this paper only results of the first experimental series of percolation and the resulting conclusions will be described in the following. (The first results from elution are going to be presented in the oral presentation.)

- It was expected, that the COD (chemical oxygen demand) in percolate from separately collected biowaste from households can be characterized by higher than COD in percolate from green garden and park waste. These expectations were met. This is caused by higher content of readily biodegradable organic substances in comparison to green garden waste. [Christ, 1999]
- Additionally the different operation of the percolation reactors regarding temperature lead to an increasing substance transfer from solid to liquid phase under mesophilic operation mode.
- The longer the retention time of percolate in reactor the higher the COD in percolate. For other parameters like chlorine, sulphate or heavy metals retention time did not have a big influence. Other parameters like e.g. temperature of operation seem to have a bigger influence on transfer of these substances.
- All parameters that have a positive influence on COD in percolate result in an increasing biogas potential in digestion process.
- With values for COD in percolate the theoretical amount of energy can be calculated that can be generated through energy recovery. The calculation offers the possibility to determine whether the energy demand for drying the solids after percolation for further processing can be met or not. The results of calculation are going to be presented during oral presentation.
- Currently other possible influencing parameters are investigated for percolation: clearances of sprinkling. For the current running experiments sprinkling clearances from 2 to 8 hours are taken into consideration. First results are going to be presented in oral presentation.

Wet pre-treatment of organic waste offers the possibility of producing a liquid phase that is qualified for digestion. Additionally a solid material fraction can be produced that might be suitable for lots of other kinds of further processing (solid fuel production, BtL-production). A discussion about the use of the solid fraction will be part of the oral presentation.

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Recycled Organic Matter (ROM) compost quality: Chemical, biological and microbiological traits

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Key words: USA compost hygiene maturity *E. coli*

Abstract

*Landfill diversion by composting of "green" wastes including grass and food has enabled states to achieve mandated recycling goals. In America, standards for quality and hygiene for intensive and organic agriculture use of non-sludge composts are still under development and 47% of states do not specify any tests. We evaluated 94 biocomposts from facilities processing 2.2 million-m³ a⁻¹ green waste. Only 20% gave cress-yield \geq 80%. Only two composts contained *Salmonella* but 37% exceeded combined pathogen expectations. Faecal coliform correlated closely with *E. coli* levels and 3 samples had detectable *E. coli*-0157-H7. Processing size of facilities had a negative correlation to hygiene quality and windrow methods had best results.*

Introduction

Composting in the United States is a strategy to reduce landfilling of organic wastes while it originated in organic farming (Heckman, 2006). Large scale composting was first attempted in the 1950's for municipal solid waste (MSW) with poor results due to contamination. New growth in the industry came about in Europe and N. America with legislated recycling mandates for bulky woody yard "green" waste, following improved understanding of source separation. Never the less, in the USA only 22 states have imposed restrictions on yard trimmings in landfills and only half have published test guidelines independent of sludge composting. This study assesses quality of for agricultural utilization.

Composting is widely assumed to have no significant risk to society but few comprehensive studies have been conducted. In the 1960's the US EPA examined thermal inactivation of pathogens and stability factors in sludge composts and the results became regulatory as the EPA-503 rule, now widely applied to all types of green composts (Brinton, 2004).

The EPA503 law assumes hygiene of sludge is inferred by using faecal coliform as a surrogate indicator for *Salmonella* (Yanko, 1988). Early correlations from 260 sludge-composts indicated pathogenic *Salmonella* was low if faecal coliform counts were below 1,000 MPN g⁻¹ TS and oxygen consumption had declined. However, these excellent early efforts predated the rise of toxigenic *E. coli* now virtually endemic in manures and found in the food chain with potentially deadly results. With greater quantities and types of ROM used in intensive growing, using a *Salmonella* surrogate model to examine hygiene is not appropriate, as green waste now contains significant *E. coli* (Doyle). With the increased compost use in horticulture, stability and salinity tests relevant to buyers and not unduly influenced by waste-industry organizations, must be developed. The reasons for this study were: increased use of compost in horticulture (Blewett, 2005), availability of updated EPA microbiological methods and new evidence that direct *E. coli* tests are more suited for hygiene tests (Doyle, 2006), evidence that unstable, immature composts permit pathogen regrowth resulting in increased incidence of *E. coli* entering the food chain (Ingram, 2007), and harmful plant effects of unstable composts used for container plants (Brinton, 2004). Phytotoxins in compost are similar to extracellular bacterial toxins resulting from incomplete microbial oxidation of ammonia from too high temperature and imbalanced pH conditions, with episodic accumulation of short-chain fatty acids from incomplete oxidation under oxygen stress especially if food scraps are composted in any quantity.

We examine quality and hygiene of non-sludge composts made in three states (WA, OR, CA) where statutory landfill diversion is practiced and two states have compost test requirements. In WA, organic wastes are classified by feedstock type, and large facilities with yard waste and food waste must perform at least one test per year for faecal coliform and salmonella. In OR, only non-green facilities are regulated at all. In CA, *Salmonella* and faecal coliform tests must be recorded annually and up to 2,000 m³ of compost may be sold without regulation. Principle markets are bulk use for soil replacement with increasing uses in agriculture (Blewett, 2005). Therefore, understanding quality of material is important for agricultural and horticultural safety and success.

Materials and methods

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Trained professionals conducted sampling over 2 yr on-site at 94 compost facilities by permission and only for market-ready product. Samples were brought chilled to a laboratory in 24h. We examined bacteria according to updated EPA and ÖNORM protocol, TN by combustion, C by LOI@550°C÷2, TS by 70°C drying @ 24h, salinity as conductivity by saturated paste extract, Solvita® after Woods End, Cress after BGK, industrial contaminants PAH and phthalates by solvent extract with LC/MS or GC/MS/MS. Some sites were re-sampled for bacteria tests after 3 and 12-weeks.

Results

Salinity of composts ranged hugely from 0.4 to 24 dS m⁻¹ as did cress growth (corrected for salinity) of 16 to 160% (Tab. 1). Composts were only moderately mature (mean C:N = 23; mean Solvita = 6.2; mean NO₃:NH₄ ratio 0.3) indicative of incomplete curing. We observed a statistically significant relationship of faecal coliform and *E. coli* bacteria for 55 paired samples ($r^2 = 0.85$, $p < 0.0001$) suggesting validity of faecal coliform tests as a generic pathogen indicator. There was no correlation of faecal to Salmonella, the latter found in only 2 facilities at low levels (<3 MPN/4g) as expected. Presence/absence of allowed manure in green composting also had no statistical relationship to hygiene quality. Three samples were positive for *E.coli*-0157:H7 confirmed with duplicate retesting. The highest amount of samples exceeding EPA-503 rule was observed in OR, followed by WA then CA (Tab. 1). Overall size had a significant impact; for facilities handling less than 45,000 mt/a, only 7% did not attain the EPA faecal coliform standard but 31% of samples from large facilities (>45,000 mt/a) did not pass the standard. Three facilities had measurable *E. coli*-0157-H7 and were large site situated in commercial vegetable regions. One of these also possessed very high *Clostridium perfringens*, an obligate anaerobe indicative of wet, faecal conditions. We resampled and retested and it was still positive for *E.coli*-0157. PAH and phthalate content increased with increasing urbanization zones. Type of windrow vs. turning, size of handling and length of composting appear to be the significant controlling factors for hygiene quality with windrow and small facilities giving best results.

Tab. 1: Characteristics of USA Green Waste Composts – Average (Min, Max)

SAMPLE REGION	Salinity dS m ⁻¹	% not passing EPA 503 Rule	Quantity <i>E. coli</i> MPN g TS ⁻¹	<i>E. coli</i> 0157:H7 POS - NEG	Cress Biomass % of Control	Phthalate µg / kg	PAH µg / kg
Region I (WA)	6.2 (0.4 – 24)	23	2.1 * (0.2 – 7.4)	not tested	46.7 (16 – 102)	103 (1 – 2,245)	156 (1 – 2,653)
Region II (OR)	3.2 (0.2 – 11)	44	1.9 (0.4 – 6.6)	POS (1)	93.3 (45 – 160)	2,275 (127 – 17625)	566 (1 – 3,722)
Region III (C)	6.1 (1.2 – 17)	20	2.3 (1.9 – 7.3)	POS (3)	55.4 (21 – 108)	5,373 (142 – 20424)	1,628 (28 – 5,840)

* Bacteria are MPN and averages are geometric mean. If < MLD then sample is MLD ÷ 2.

Discussion & Conclusion

Of the 94 composts we tested, all varied enormously in test qualities, with 37% falling into a hygiene-restricted category by excessive pathogen indicators. Salinity and maturity appeared to be the greatest potential limit to improved horticultural use. Facility processing size and management are important factors for quality. More effort is needed to understand and regulate compost quality.

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Earthworms and Microorganisms: Disentangling the Black Box of Vermicomposting

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Key words: direct effects; functional diversity; microbial activity; carbon mineralization; indirect effects

Abstract

Here we show the direct and indirect effects of earthworm *Eisenia fetida* during vermicomposting of pig slurry. We found that earthworms promoted significant increases in microbial biomass and activity during vermicomposting. However, in casts (direct effects), we found an increase in microbial biomass and a decrease in microbial activity. After inoculation pig slurry with vermicompost (indirect effects) we observed the same pattern of increase of microbial biomass and activity that found in vermicomposting but to a lesser extent.

Introduction

Microorganisms are largely responsible of organic matter decomposition, but earthworms may also affect to rates of decomposition directly by feeding on and digesting organic matter, or indirectly affect them through their interactions with the microflora, basically involving stimulation or depression of the microbial biomass and activity (Edwards, 2004). Here we present the results of three experiments which tried to separate between the direct and indirect effects of earthworm on decomposition of organic matter. We used the vermicomposting process as a model to study the relationships of earthworms and microorganisms (Dominguez, 2004).

Materials and methods

To do this we designed experimental continuous feeding reactors. The reactors were comprised of modules that were added sequentially to the system. The modules, which resembled sieves, were made of PVC - the external diameter of each was 30 cm with a height of 2 cm giving a volume of 1413 cm³. The bottom of the modules was a mesh size 5 mm, which allowed earthworms to move between modules. Each reactor was initially composed of one module containing vermicompost, in which earthworms were placed, and another module containing a layer of 1.5 kg of fresh pig manure (300 g of dry mass, moisture content 80±10%). We set up a batch of six reactor, three without earthworms (control) and three containing 500 mature earthworms (ca. 90±10 g, fresh weight) (*Eisenia fetida*) each. At the end of the experiment (i.e. after 36 weeks), the reactors comprised 12 modules with an increasing gradient of age, resembling a soil profile, from upper to lower layers as follows: 2, 4, 7, 8, 11, 18, 21, 25, 27, 29, 33 and 36 weeks. For sampling, the reactors were dismantled and the modules isolated to avoid the earthworms escaping. Five samples of substrate per module were taken at random and gently mixed for biochemical analyses, i.e. microbial biomass-C, ergosterol content, basal respiration (Alef and Nannipieri, 1998). To test the existence of direct effects we analyzed the changes in microbial biomass and activity in fresh casts produced by the earthworm *E. fetida* fed with pig slurry. To test the existence of indirect effects we inoculated pig slurry with vermicompost produced by the earthworm species *Eudrilus eugeniae*, *E. fetida* and *E. andrei*. We used 0, 2.5 and 10% doses of inoculation, and prepared 105 microcosms, that were sampled destructively after 15, 30 and 60 days.

Results

Earthworms promoted an increase in the biomass and activity of microorganisms, and also favoured fungal growth in the youngest modules, effect that was higher in reactors fed with 3kg of pig slurry. In older modules earthworms reduced the biomass and activity of microorganisms, effect that was higher in reactors fed with 1.5 kg of pig slurry (Figure 1). Earthworms increased microbial biomass of pig slurry significantly (from 14000±500 to 16000±700 of casts), and reduced significantly ($p<0.01$) the microbial activity (from 810±15 to 730±10 of casts), showing the importance of direct effects. Inoculation of vermicompost into pig slurry modified the microorganisms, separating clearly the microbial community depending on type of vermicompost, dose of inoculation and time of incubation (Figure 2). Thus, microbial biomass increased depending on percentage of inoculation and type of

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vermicompost, showing the samples inoculated with vermicompost of *E. fetida* and *E. andrei* the highest values, and the same happened with the microbial activity (Figure 2).

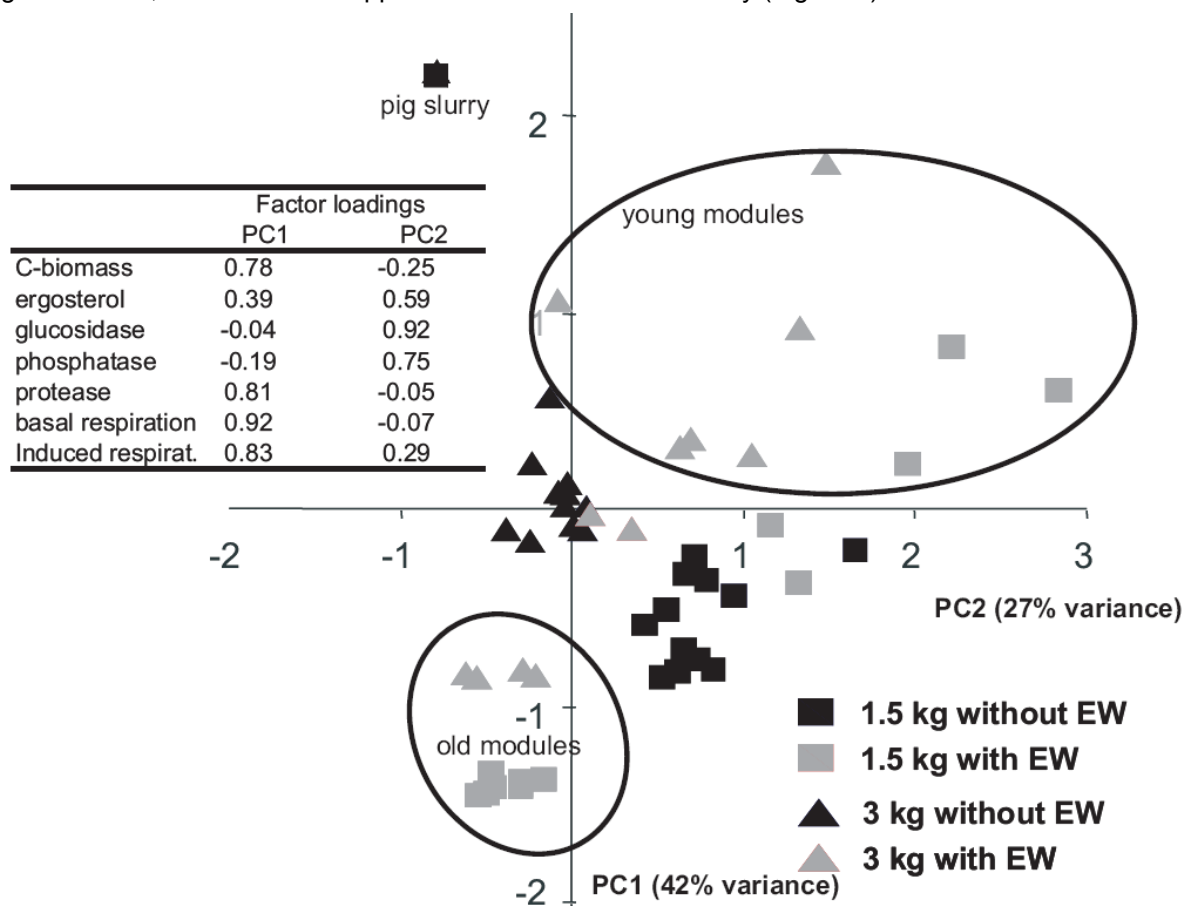


Figure 2. Principal component analysis with the microbial variables analyzed (biomass and activity) during vermicomposting of pig slurry, with the factor loadings for each principal component.

Squares and triangles represent modules of reactors fed with 1.5 kg and 3 kg of pig slurry respectively. Black symbols are reactors without earthworms and grey symbols reactors with earthworms.

Discussion

We found that the effect of earthworms on organic matter decomposition was clearly separated in two stages. In the first stage, corresponding to the 2 to 18 week-old layers, in which earthworms were still present, we recorded the highest values of microbial biomass and activity. The second stage, corresponding to the 21 to 36 week-old layers, characterized by the absence of earthworms and the stabilization of organic matter, showed a intense decrease in microbial biomass and activity (citas Aira et al. 2007). Further, the increase in fungal populations may result in an improved rate of cellulose decomposition (Aira et al., 2006). Results from casts experiment (increase of microbial biomass and decrease of microbial activity) indicate that direct effects of *E. fetida* produce changes in microbial populations that will influence the dynamics of organic matter degradation. The decrease in microbial activity can be attributed to the reductions of organic C and N (Aira and Dominguez, 2008). Inoculation of vermicompost into pig slurry modified the microbial community functioning, separating clearly the microbial community depending on type of vermicompost, dose of inoculation and time of incubation. These changes were in the same direction, first increase and then decrease, than those found in the vermicomposting experiment suggesting that indirect effects of earthworms are able to alter the dynamics of pig slurry decomposition. However, the extent of these effects was not as higher as those found in vermicomposting; this, together the results of casting experiment suggest the existence of more factors governing the relationships that earthworms and microorganisms establish during vermicomposting.

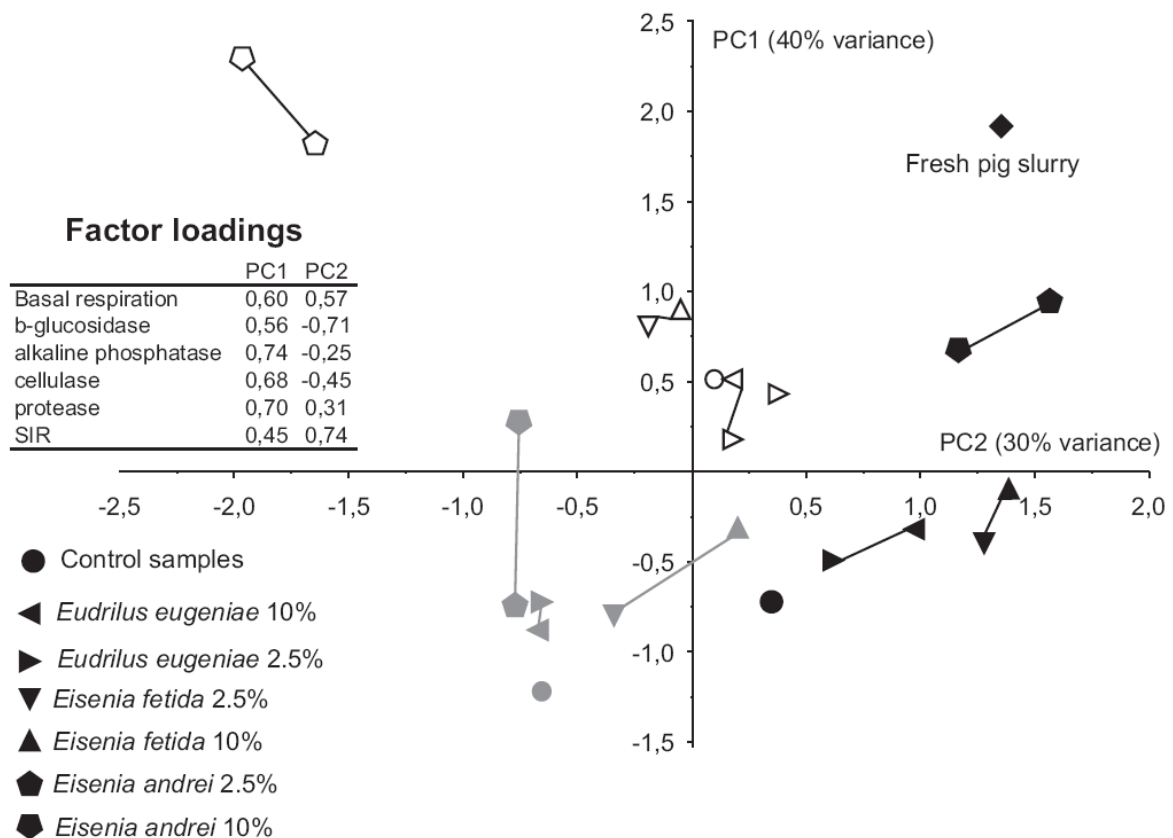


Figure 3. Principal component analysis with the microbial variables analyzed (biomass and activity) after inoculation of pig slurry with vermicomposts, with the factor loadings for each principal component.

Pig slurry was inoculated at 0 (control), 2.5 and 10% with vermicompost produced by the earthworms *Eudrilus eugeniae*, *Eisenia fetida* and *Eisenia andrei*. Black, grey and white symbols are samples after 15, 30 and 60 days of inoculation.

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A novel vermicompost based formulation for bioinoculants with added plant and microbial growth promoting natural products

Alok Kalra¹, Mahesh Chandra, Khanuja S.P.S.

Key words: Carrier; *Rhizobium meliloti* and Vermicompost

Abstract

Although peat is the carrier of choice for the bioinoculants like *Rhizobium* it is not ubiquitously distributed and a more readily available substrate. Our preliminary observations while working with vermicompost produced from various wastes on microbial populations indicated that vermicompost from distillation wastes of essential oil bearing crops, supports higher levels of microbial populations compared with any other manure/ compost. The present study has tried to establish the usefulness of such vermicomposts as carrier *Rhizobium*. *Rhizobium meliloti* Rmd 201 (an efficient N fixer) was inoculated to sterilized vermicompost (granular solid) and its aqueous extract (liquid) separately. Vermicompost supported the cells of *R. meliloti* up to 5.8×10^8 after 180 days period at 28 °C compared to 2.1×10^8 in charcoal (powdered). We have earlier established that calliterpinone (CT), a plant growth promoter and a natural product CU (CIM-1865) enhanced the population of *Rhizobium meliloti* Rmd 201 by about 10 folds when media (YEMB) was supplemented @ 12.5-25 µL/ml. Efforts were therefore made to further improve the population density of *R. meliloti* Rmd 201 in vermicompost by addition of above said products. Potential of vermicompost as carrier material towards supporting increased population size with extra nutrient availability and further by improving populations of bioinoculants by supplementing the carrier with microbial growth promoting natural products was established.

Introduction

Carrier refers to a substance which can sustain appreciable number of bioinoculants for a certain period of time. A suitable rhizobial carrier should have a good water holding capacity, good aeration characteristics, support bacterial growth and survival, be non-toxic, easily sterilized, manufactured, and handled in the field, environmentally friendly, and have good storage quality. Peat possesses a privileged position in the manufacturing of legume inoculants because of many advantages associated with it. However, there are no large scale deposits of peat in India and therefore any commercial exploitation of this as carrier seems to be a remote possibility. Considering the usefulness of organic manure in today's world of organic and their easy availability the present study investigates the suitability of granular vermicompost as solid carrier material and its water extract for liquid carrier material using highly efficient strain of *Rhizobium meliloti* Rmd 201, for inoculant production.

Materials and methods

Three carrier materials, viz. granular vermicompost (GVC), farm yard manure (FYM) and charcoal (CHL) were used as carrier. These carriers were sterilized in an autoclave (121°C, 1 h) for three consecutive days. The bacterial suspension (2.6×10^9 - 5.6×10^9) of *R. meliloti* Rmd 201 in sterile demineralized water was mixed with carriers (0.65 mL g^{-1}), stored in high density polythene bags at 28°C. For liquid carriers vermicompost aqueous extract (1:2.5) was used. The viable count of *Rhizobium* was monitored periodically by conventional viable plate count method using YEMA (Yeast extract mannitol agar) medium.

Results

Initially population in all test carriers was between 1.01×10^9 - 2.0×10^9 CFU g^{-1} which increased sharply (2.4×10^9 - 4.7×10^9 CFU g^{-1}) in first 10 days and slowly declined thereafter. The rhizobia count again increased after a month and then showed a consistent decline except in GVC where an increase was again noticed after 4-5 months. Maximum viable population of rhizobia could be recovered in GVC followed by charcoal and FYM after 6 months of incubation (Fig.1A). Attempts were also made to use vermicompost extract as a liquid carrier for its suitability as carrier for rhizobial inoculants. Fig.1B. reveals that vermicompost extract (VCE) maintained the population of rhizobia for a longer period. In this carrier (vermicompost extract) population of rhizobia was monitored upto one year and it was observed that a population of 1.0×10^6 - 2.1×10^6 cfu g^{-1} could be maintained even after one year. A priori, we observed that CU and CT could enhance growth of rhizobia and other bacilli.

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These two natural microbial growth promoters were incorporated into GVC and VCE to observe their usefulness in maintaining higher population of rhizobial inoculants for longer periods. CU improved the population of rhizobia upto 10 fold in GVC as carrier compared to GVC alone. Initially, upto 30 days this natural product enhanced the growth of rhizobia at faster pace and thereafter, population of rhizobia declined upto 120 days; however, the population could be maintained between 1.23×10^9 to 2.28×10^9 cfu g^{-1} for the remaining period i.e., 180 days. Similar enhancements in rhizobial population were also noticed when CU and CT were incorporated in liquid carrier material. Incorporation of CT increased population of rhizobia upto 100 fold after 5 days of inoculation in liquid carrier when compared to VCE alone Population size of 8.6×10^7 - 9.6×10^7 CFU ml^{-1} could be maintained in VCE after 330 days when supplemented with CT.

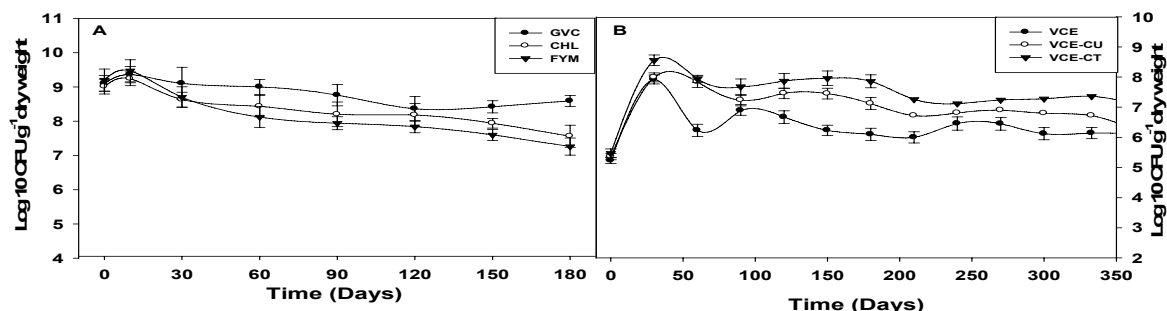


Figure 1: Survival of *R. meliloti* Rmd 201 in different solid carriers (A) and liquid carriers (B).

Discussion

The potential of vermicompost as carrier of *Rhizobium meliloti* Rmd 201, for inoculant production is demonstrated in present investigation. It supported good growth of rhizobia till about 180th day; a population of 10^8 . This is probably attributable to higher nutrient content and high water holding capacities of GVC, which according to Smith (1992) are two key characteristics of good carriers. Populations we observed with all carriers are meeting the standards set by most countries as being acceptable, ranging between 1×10^7 to 1×10^9 rhizobia/g inoculant (Rebah et al., 2007 Smith, 1992).

Vermicompost extract proved it self as a liquid carrier material as this could maintain the population of rhizobia for a longer period. Walley et al (2004) reported that the liquid inoculant for lentil and field pea was as effective as the traditional peat inoculant. CU and CT, the natural products developed at CIMAP were also helpful in further increasing the population of rhizobia in VCE.

Conclusions

Vermicompost based formulations of bioinoculants containing microbial growth promoting natural products would be better choice as these are derived for cheap and easily available carrier material, support the growth and survival of bioinoculant for longer period and apart from benefits provided by bioinoculants would provide extra nutrition to plant and improve soil health.

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New method for evaluation of impurities in compost

Maria Thelen-Jüngling¹

Key words: compost, quality, impurities, evaluation; surface area

Abstract

Impurities are undesirable ingredients in compost because they impair the typical appearance of the product, its utility and its marketing value. The evaluation of these impurities by determining their proportional weights in the compost will lead to false estimations if most of the impurities are light materials. In the course of the project described here we were able to prove that the surface area of the impurities is a suitable parameter for estimating the light material impurities. It can be assumed from these investigations that a visual strong contamination of the compost can be ruled out if the surface area of all the isolated impurities does not exceed 25 cm²/l of fresh matter.

Introduction

The optical appearance of compost is the most important quality criteria for the user and the deciding factor for accepting this product. Impurities such as glass, plastics, rubber, metals etc. are undesirable. In line with the biowaste regulation and the quality requirements of the RAL mark of quality a threshold value was determined for impurities in compost. Utilizing compost on cultivated soil is only permissible if the content of impurities does not exceed 0,5 weight-% of the dry matter. The impurity content is usually determined by gravimetric methods. Practically, however, this method of determining the weight of the impurities for a meaningful assessment was only suitable if most of these impurities were specifically heavier materials such as glass and metal. (fig. 1)

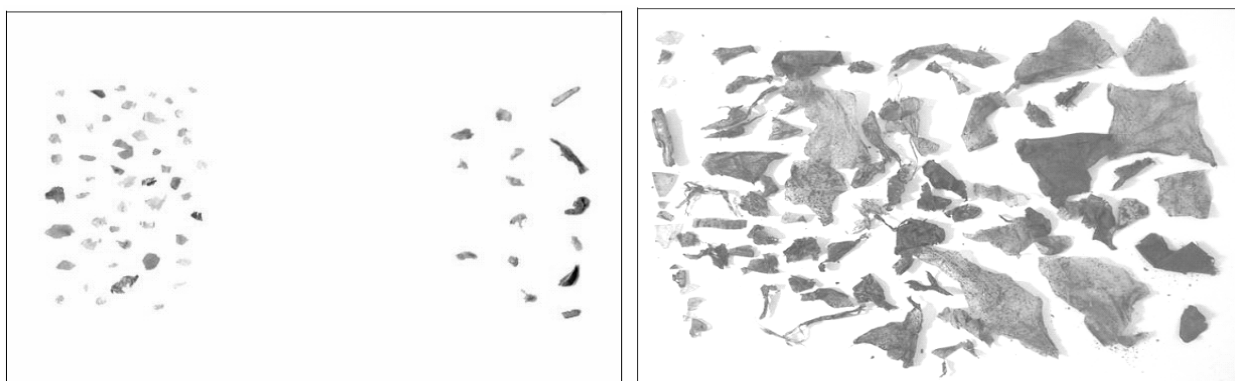


Figure 1 Comparison between equal spreading with heavy and light impurities (left side) and spreading with mostly light impurities (right side). Both examples show a gravimetric content of impurities of 0,45 weight-% dry matter

Materials and methods

In the course of a first pilot project conducted by the Bundesgütegemeinschaft Kompost e.V (German Quality Assurance Association for Compost) a representative selection of 220 compost samples were taken for an visual assessment of their degree of contamination with the help of defined classes of rating as well as for a quantitative assessment of the impurities over the surface area of the isolated disturbing materials. Another project was conducted in the year 2005 while doing the routine sampling of compost for the RAL-Gütesicherung (RAL-Quality Assurance). A total of 727 samples were thus obtained for an additional determination of the surface area of the isolated impurities.

The visual gradation was divided into three classes. Class 1 stands for no or only slight contamination with impurities, class 2 was noticeably contaminated and class 3 strongly contaminated with foreign materials (fig. 2).

Reasonably the determination of the observed surface area of the impurities is done subsequent to the gravimetric determination of the impurities, since the individual impurities are sorted out of the sample for this purpose. Depending on the grain size of the compost to be investigated, 1 to 3 litres of sample must be dried at 105°C and then sieved to 2 mm. The fraction >2 mm is then manually sorted

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out. The sorted out impurities are separated according to categories, weighed and the percentage weight on the weight of the whole sample is calculated. For the subsequent determination of the surface area the sorted out materials are loosely spread out on a white surface (e.g. plastic slab) with a known area. Care should be taken that the individual materials do not overlap. In addition to the cumulative surface area of all the impurities, the surface area of the individual categories is also determined. For this purpose the individual categories are spread on the surface in segments. Digital photographs of the separate samples are then taken. Finally with the help of adequate software (equipped with a photo processing programme) the total surface area of the impurities is calculated from the degree of coverage of the white surface with a known area.

Results

As result of the visual grading of impurities we found as expected no relation between the visual grading and the weight. However, with the observation of the surface area, statistically confirmed correlations between the grades and the cumulative surface area have been proved. (figure 2).

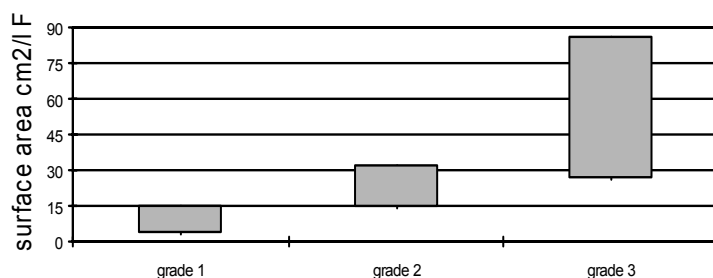


Figure 2 Visual grading and surface area of impurities

Conclusions

In both projects, determining the surface area of the impurities proved to be the most suitable parameter for determining the visual effective contamination of compost. This is especially true for the light fractions of impurities. In order to adequately assess the light material impurities that are optically recognisable, the parameter surface area has been proved as the most suitable and significant method when compared to the weight determination method. It has been suggested to include the surface area of the impurities as an added parameter in the results of both projects. 25 cm²/ litre FM was suggested as standard value for the tolerable maximum surface area because in the second project with practical experience this value was suitable for detecting strongly contaminated composts and corresponds to the results of the visual grading.

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Session P3:

Use of composts and digestates :

Choice of the product depending

of utilization strategy and aim

Use of compost and digestate: choosing the product depending on utilisation, strategy and aim

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Keywords: quality, compost, digestate, utilisation, criteria

Abstract

The introduction of separate collection in Switzerland was brought about in 1986 by the imposition of limit values for heavy metals in compost. But this did not guarantee a market for the products. The main problem here is that the production process was (and still is) financed by the gate fees for the waste, so the commercial success of compost production depends very little, if at all, on the sale of the product. As a consequence, the transition from waste to product does not come as easily as one could wish. For many potential users of the product, this “original sin” constitutes the main obstacle.

The basic operational requirements to produce good quality compost are relatively clearly defined: in Switzerland, a mandatory positive list has been drawn up for the raw (input) materials, any waste not on the list requires a specific authorisation for it to be accepted by a composting or digestion plant. Hygiene and process requirements have been laid down. But this still does not suffice to guarantee a risk-free use of the product.

The QAS motto “Quality is fitness for use” means that one must first define the ranges of application of a product, before one can outline its quality criteria. In Switzerland, a working group has recently been formed, to lay down new quality guidelines for compost and digestate. Not only will existing guidelines be compared and assessed, but the expectations and wishes of producers and users will be integrated in the discussion, so a global consensus can be reached.

The last 10 years saw the birth of several quality standards schemes in Switzerland. But since the branch could not agree unanimously on any one proposal, we now have the unique chance of improving the system, since the new working group includes representatives of all the interest groups concerned. There is also hope that the debate taking place in Switzerland will stimulate and be stimulated by the ongoing discussion on quality standards in the European Union. The Swiss scheme will probably be rather similar to the product categories defined by the German BGK. Five categories are proposed: a) liquid digestate, b) solid digestate, c) compost for agricultural applications, d) compost for use in horticulture and e) compost for covered cultures. The specifications and limit values for each categories remain to be formulated.

Introduction

For the vast majority of products, mandatory compliance with a product definition comprising a series of minimal requirements is taken for granted, i.e. milk must contain a minimum amount of milk fat or protein and conform to certain hygiene standards. In waste treatment processes, it has been very difficult to impose the idea of quality criteria for the end-products, since there is a gate fee for handing over the waste which covers most, if not all, the costs of treatment, while the products are often given away for free. So existing requirements were generally restricted to limit values for heavy metals and other similar “negative” minimal precautionary requirements. They gave practically no description of what “positive” qualities and properties the product should have.

There are a few exceptions in Europe, where attempts were made to define quality standards for products from the biowaste sector according to the ISO concept “quality is fitness for use”. These example will be discussed in a later chapter of this report. In Switzerland, the Association of Swiss Composting and Digestion Plants (ASCP) published its Guidelines in 2001, and they will serve as a starting point for the new guidelines. Furthermore, in view of the present trend towards globalisation, it seems sensible to define guidelines that contradict existing recognised quality criteria as little as possible.

Thanks to the recent national studies that have been carried out, we have the unique chance today of possessing a current picture, both very broad and very detailed, of the analytical profile of Swiss composts and digestates. We can use it to decide which products can be applied where and which must be excluded from certain application categories. One important step here is to integrate in the

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assessment the new products coming from the increasingly numerous anaerobic digestion plants. With appropriate post-maturation, they can often acquire the qualities of valuable compost products. But it is important to ensure that no insufficiently stabilised products are used in horticulture in the future, as these can damage the cultures and therefore the reputation of the entire compost market. The aim of any quality guidelines must be to generally ensure problem-free use of the products, so as to guarantee a favourable market in the long term, with a constant demand for good-quality products.

Materials and methods

The report aims to give you an insight into the workshop where the new Swiss quality guidelines are taking shape. Several literature reviews and surveys are being carried out, to ascertain what current standards and requirements are. Furthermore, the results of the national research projects were subjected to a statistical analysis by Prof. Stahel at the Swiss Federal Institute of Technology in Zurich (ETHZ), where relations between the various results were brought to light. But this is will not be described here. The other part of the work, which we will discuss in more detail, consists of finding a consensus among a heterogeneous group. (to be completed).

Apart from the ASCP Guidelines, the categories and criteria of the German BGK will also be taken into account. They were defined in cooperation with Applied Science Institutes specialised in horticulture. Quality assurance schemes and guidelines from neighbouring countries will also be integrated in the discussion, in particular those proposed by the Austrian KGVO, the Belgian VLACO, the Dutch VAM and the French ADEME. These schemes, however, do not place the accent in their classification on the applications for which the products are destined.

Results

The ASCP Guidelines (2001)

With these guidelines, the ASCP, in collaboration with the Swiss Biogas Forum, intended to define the characteristics a compost must possess to be used in agriculture, in horticulture, market gardening and landscaping, or in covered cultures. Covered cultures and private gardening require the highest quality and degree of maturity. Slightly lower standards suffice for commercial horticulture. The minimal statutory requirements of the Federal Research Station of Liebefeld (FAC, 1995) apply for agricultural and other uses.

The guidelines were intended as complementary to the mandatory FAC 1995 instructions, and in no case did they replace them. The minimal quality requirements were amended and the meaning of the terms “degraded” (in German, “verrottet”) and “digestate” (in German, “Gärgut”) were further specified.

The guidelines introduced a distinction between digestate (the solid residue of anaerobic digestion, with no post-maturation) and compost, based on product specificity and the $\text{NH}_4\text{-N}$ content. Several hundreds of analyses have clearly shown that digestates with no post-maturation contain higher levels of $\text{NH}_4\text{-N}$ than compost, well over 300 mg per kilogram fresh weight. As a further practical criterion for the definition of the term “degraded” in the definition of a compost, the guidelines proposed that, except for wood, no other feedstock be recognisable visually or by smell. For example, it must not be possible to recognise the species of leaves. Compost complying with all the requirements of the guidelines can be obtained from digestate which has undergone state-of-the-art aerobic composting.

A further novelty of these guidelines, going considerably farther than any of the standards formulated by the FAC, are the quality requirements for compost used in horticulture and landscaping, both for outdoor and for covered cultures. Beside chemical and physical parameters, normalised biological tests were also proposed. With increasing maturity, the salt content and pH should decrease. The nitrate to ammonium ratio should increase due to nitrification. The decreasing solubility of the humic substances that form during maturation result in an increasingly lighter colour of the aqueous extracts. The advanced maturation drastically improves the stability and plant compatibility of the product.

To obtain a high-quality finished product requires not only state-of-the-art processing, but also a correct choice of feedstocks. Only materials with low levels of pollutants should be used. This excludes wastes susceptible of being highly contaminated, such as sewage sludge, or waste from street cleansing. The ASCP and Biogas Forum recommend that the feedstock and additives be declared. The ASCP Guidelines have been put into practice in the last years through the “Training – Quality - Controlling” concept promoted by the association.

Table 1. The different qualities of compost and digestate from biodegradable waste, according to the ASCP Guidelines of 2001.

Criteria	Agricultural use		Compost for horticultural use	Compost for covered cultures and private gardening
	Digestate	Compost		
Minimal quality	Complies with minimal quality requirements according to (FAC 1995)			
Heavy metals	< Osubst limits ¹⁾			
Impurities	Complies with minimal quality requirements according to (FAC 1995)			
Sanitation	Fulfilled	Complies with minimal quality requirements according to (FAC 1995). With temperature protocol		
Nutrients: N, P ₂ O ₅ , K ₂ O, Mg, Ca	X	X	X	X
Decomposition	Feedstock unrecognisable, except for wood			
DW (Dry matter)	X	X	> 50 %	> 55 %
OM (Organic matter)	X	X	< 50%	< 40 %
pH	X	X	< 8.2	< 7.5
Particle size	X	X	< 25 mm	< 15 mm
Bulk density	X	X	X	X
Colour of extract (humus number)			recommended	
Salinity	X	X	< 4 mS/cm	<2.5 mS/cm
Total N	X	X	> 10 g/kg DW	> 12 g/kg DW
C/N ratio			X	X
NH ₄ -N	X	< 300 mg/kg FW		
NO ₃ -N	X	X	> 40 mg/kg FW	> 50 mg/kg FW
NO ₃ -N / NH ₄ -N ratio			>2	> 20
NO ₂ -N			< 5 mg/kg FW	< 2.5 mg/kg FW
Germinating weed seeds			< 1 per litre	< 1 per litre
Plant compatibility:				
Cress (open)			> 70 % of ref.	> 90 % of ref.
Cress (closed)			> 25 % of ref.	> 50 % of ref.
Salad			> 50 % of ref.	> 70 % of ref.
Bean				> 70 % of ref.
Ray grass				> 70 % of ref.
Disease suppressivity test				recommended

¹⁾ Swiss Ordinance on Substances, now replaced by the ORRChem.

Shaded cells: minimal requirements. X: must be specified

Status of quality assurance for biowaste products in the EU

The central role of quality assurance can be observed in countries with a developed composting system, such as Austria, Germany, Denmark, the Netherlands, Luxembourg, UK and Belgium. These countries have established extensive quality management systems for composting and digestion plants, in which around 620 plants, with a composting capacity of 9 million tons and an anaerobic digestion capacity of 2 million tons, participate today. Several others countries, such as Hungary, are at the conceptual design stage.

Table 2. Status of quality assurance of European composting and digestion plants (2004)

Country	Plants under quality assurance schem ¹⁾	Plants with quality label or certificate
Austria	8	7
Flanders/Belgium	24	10
Luxemburg	3	3
The Netherlands	22	4
Germany	450 compost+ 50 digestion	428 compost + 40 digestion
Sweden	2 compost + 8 digestion	4 digestion
UK	45	20

¹⁾ The table includes plants that have applied for a quality label or certificate, but for which the certification process is not yet finished

Type of control systems

An important difference between the various European systems lies in how much the quality assurance system takes the compost production process into account. Thus, while the philosophy of the German RAL quality label is to concentrate on assessing the quality of the end-product, in the Netherlands and in Belgium, both process and product are controlled, albeit with differences in focus.

Thus, in Belgium, a compost plant applying for the quality label will be monitored for two years before being maybe awarded it: while production is continuously monitored during the first year, only the quality of the compost produced is controlled during the second year. In the Netherlands, the certification process for the quality label comprises an in-depth internal quality monitoring of the compost production, with weekly tests of the parameters of each compost batch.

Table 3. Range of control systems for composting plants in Europe (Status 2005)

	Production control	Product control
Austria	Compost Ordinance	KGVÖ
Flanders/Belgium	VLACO - during the first year of operation	VLACO – beginning with the second year
Denmark	-	Plant Directorate
France	According to ISO 9000 principle in the Qualorg research project	According to ISO 9000 principle in the Qualorg research project
Germany	BGK ¹⁾	BGK
The Netherlands	KIWA	KIWA
Sweden	RVF Certification	RVF Certification
UK	TCA Standard	TCA Standard

¹⁾ only for hygiene issues.

KGVÖ, VLACO, BGK, KIWA, RVF, TCA are the bodies responsible for the quality assurance programmes in their respective countries

A similar trend can be observed in Austria, where the quality label programme requires that a product and process diary with nearly one hundred positions be kept. This goes to illustrate the current trend towards more production control in the European quality assurance schemes.

Quality criteria

The quality criteria for compost vary among European countries concerning the type of and range of requirements (e.g. process and/or product parameters) and the limit values (e.g. for pollutants). In the voluntary and statutory compost standards that apply in Austria, Canada, Germany, Spain, Sweden and the Netherlands, the **heavy metal content** is used to determine the quality class of the products. The **type of raw material** is a defining criterion in Austria, Belgium, Denmark, Germany, Italy, Spain and Sweden. In Germany and Austria, compost types are further delimited, **based on the range of application** (Table 4).

Experience shows that if compost qualities are defined based on their heavy metal content, only the best quality will be asked for. Large quantities of lesser quality compost, though perfectly fit for various uses, will nevertheless fail to find a market. Quality classes based on the raw materials (Flanders/Belgium), on the properties of the product or on its ranges of utilisation (Germany) will more effectively meet the requirements of the compost market.

Table 4. Classification of compost and digestate quality in Europe (2005)

Country	Types and quality classes
Austria	Quality Class A+ (for organic farming), class A (for food production) and class B (for non-food production) based on different raw materials and heavy metal contents
Flanders/B	Yard waste compost and vegetable, fruit and garden (VFG) compost
Denmark	Organic household waste compost with no classification up to now. No quality criteria for green/yard waste compost necessary.
Germany	Biowaste Ordinance Type I and II with different heavy metal contents (statutory) Voluntary RAL Standard: fresh and matured compost, mulch and substrate compost, liquid and solid digestate
Italy	Source separation or not
Luxembourg	Fresh and matured compost
Netherlands	Compost and very good compost
Sweden	Voluntary: compost and digestate
UK	Voluntary: the Compost Association Standard defined by heavy metal content

Heavy metal content

Table 5 reveals a very interesting development: the heavy metal limit values in Europe are drawing closer and closer. Reaching a common European quality standard within a European biowaste legislation becomes a progressively more realistic scenario. The European Commission has released a detailed study on compost contamination, which proposes precautionary limits for heavy metals to avoid pollution of soils, but dismisses the need for similar limits on organic pollutants (Amlinger 2004).

This new study monitored levels of heavy metal and organic pollutants in biodegradable wastes used to produce compost, in compost itself, and in soils treated with compost. It suggests precautionary limits for seven heavy metals (see table 5). The limits proposed take into account a long-term sustainable use of waste-derived composts, as well as the qualities achievable by the compost plants providing the organic waste is source segregated.

These limit values aim to avoid contamination of soils by imposing separate collection of the waste destined for compost production. Comparison of the limit values with the last row in table 5 clearly illustrates how the pollutant level of a compost can be divided by almost 4 when it is produced in this way, compared to a compost obtained from mixed waste.

Table 5. Heavy-metal limit values in Europe (2005)

Land	Quality standards [mg/kg dm]	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Austria	Biowaste Ordinance Class A	1	70	150	0.7	60	120	500
B (Flanders)	Agricultural Ministry	1.5	70	90	1	20	120	300
Denmark	Agricultural Ministry	0.4	-	1000	0.8	30	120	4000
Germany	Biowaste Ordinance Type II	1.5	100	100	1	50	150	400
Luxembourg	Environmental Ministry	1.5	100	100	1	50	150	400
Netherlands	Class "Standard Compost"	1	50	60	0.3	20	100	200
Spain (Catalonia)	Class A (Draft)	2	100	100	1	60	150	400
Sweden	RVF Quality Requirements	1	100	100	1	50	100	300
UK	TCA Quality Label	1.5	100	200	1	50	150	400
EU	Proposal of EU study ¹⁾	1.3	60	110	0.45	40	130	400
Switzerland	Agricultural Ministry	1	-	100	1	30	120	400
Germany	Mixed waste compost ²⁾	5.5	71.4	274	-	44.9	513	1570

¹⁾ Amlinger et al. (2004): Heavy metals and organic compounds from wastes used as organic fertilisers. Study on behalf of the European Commission

²⁾ German means in former mixed waste composting plants, source: LAGA Merkblatt M10, Status 10/84

Quality labels and certificates

Those plants which pass the quality assurance assessment successfully are awarded a quality label or certificate, which they can then use in their public-relations activities and as an advertisement for their high-quality products.



Figure 1: Quality labels and certificates for composts and digestates in the EU

Compost quality, marketing and public relations

Marketing of compost and public relations around composting also require the quality of the product to be standardised. Composts which have been tested in a quality assurance system meet these requirements because:

- Quality assurance is always a good basis for sales promotion, public-relations work and a constitutes a good tool to establish confidence in any product, not just compost.
- The quality label helps to establish a branded “quality-tested compost” and a positive compost image.
- Regular analyses during compost production guarantee a product of constant high quality.
- Standardised analyses carried out in accordance with specified methods enable a nationwide objective assessment of the compost.
- The investigation results form the basis for the product declaration and the application recommendations.

The result is a compost of defined quality, which is therefore marketable and saleable on a large scale.

Goals of a European quality assurance system

The Revision of the EU Waste Framework Directive intends to stipulate criteria and a standard for the end of waste status i.e. the point at which a recycled material - e.g. compost - is no longer waste, but becomes a product which can be sold freely on the European market. Every standard is as good as its monitoring. So, the need for monitoring these standards is an incentive towards establishing a consistent and independent quality assurance scheme for compost. The linkage of the product property of compost to an independent product certification – which is what is intended by ECN with its European quality assurance initiative - would essentially contribute to legal certainty and to relieving the authorities of control tasks.

The goals of a European quality assurance scheme (ECN-QAS) include the definition of an common basic product standard, the harmonisation of essential process requirements and the monitoring of all this by an independent and regular control.

The monitoring of the plants will make available data and knowledge about the quality situation which will be comparable throughout Europe. Existing European quality assurance schemes will be given a common basis by the ECN-QAS and countries which are starting to build up their scheme will obtain support through it.

Characteristics of the European quality assurance scheme (ECN-QAS)

The ECN-QAS constitutes an independent quality assurance scheme and includes basic requirements for a European product standard for compost. National quality assurance organisations which intend to participate in the European quality assurance scheme must guarantee they will submit to the ECN-QAS requirements.

It is expected that each national quality assurance organisation will be recognised by their respective national authorities. The national quality assurance organisations will be responsible for monitoring the plants and the products and for awarding of the quality label. The national organisations remain free to go beyond the ECN-QAS requirements.

The European quality assurance scheme includes:

- regular assessment of the production plant by a certification body (national quality assurance organisation), including some process requirements;
- regular sampling and analysis of the final product by independent laboratories and, additionally, appraisal of the results by a certification body;
- issuing of standard certification and documentation forms by the certification body, covering the required qualities of the product, the national legal requirements which must be fulfilled, the necessary product declaration and information about best-practice application methods and quantities;
- awarding of the quality label by the certification body.

Figure 2 illustrates the four pillars on which the European quality assurance scheme is based:

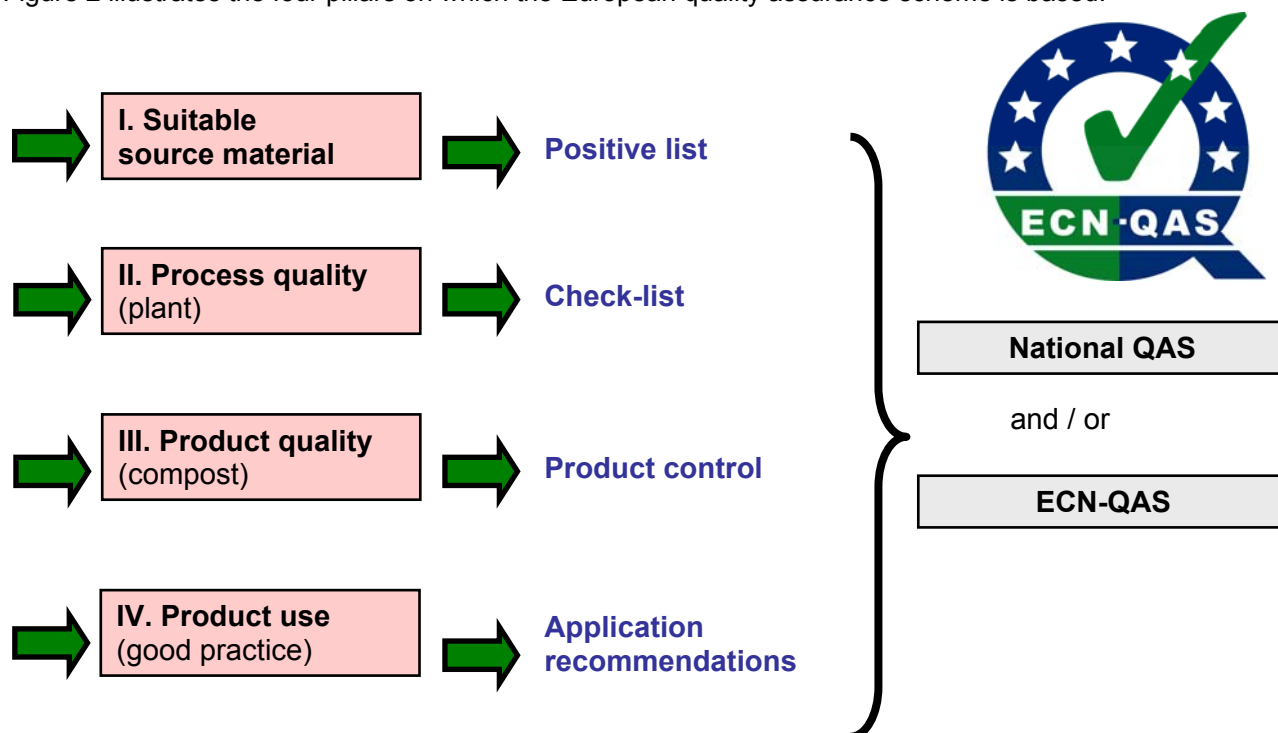


Figure 2. Concept of the European Quality Assurance (ECN-QAS) for compost and digestate

The European Compost Network is developing a quality management handbook, in which are laid down both the requirements for process and product control and those with which the national quality assurance organisations must itself comply. The first edition of the quality management handbook assurance for compost will be published in 2008.

The end-of-waste standards (as intended in the revision of the EU Waste Framework Directive) are preconditions towards demonstrating that the high quality of recycled biowaste can meet both customer requirements and the standardisation needs of recycled products on the market. They have

to be supplemented by a quality assurance system to monitor them on a European level, which is what the European Compost Network ECN has started to prepare. Together, this will give European legislation the chance to grant product status to end-products resulting from the composting of separately collected organic wastes. This will gradually cancel out the negative waste image attached to those waste derived products and help to sustainably establish compost as a valuable organic fertiliser, soil improver and component of growing media.

Discussion

Our premises for the new Swiss guidelines are the following:

1. All products included in the definition of compost and digestate are produced from source separated materials and comply with the limit values for heavy metals and the reference values for organic pollutants laid down in the Swiss Ordinance on Fertilisers and the Ordinance on Risk Reduction related to Chemical Products (ORRChem).
2. The hygiene criteria of the positive list are complied with, meaning that all the facilities that process material belonging to classes other than a (innocuous) can prove that sanitation has been perfectly carried out. No product should be marketed in the particularly sensitive fields of horticulture and hobby gardening without proof of sanitation.
3. The level of foreign materials must lie below the limit values of the Fertiliser ordinance or the ORRChem. For most clients, a reference to a maximal value does not suffice, products must also be visually exempt of foreign materials, if this is technically feasible.
4. These criteria must apply to the pure products and not to mixtures, where compost or digestate are in effect diluted with other materials, such as peat, sand or earth.

With these premises, a classification according to pollutant levels does not make sense, since the minimal requirements are already very severe. The criteria used to classify the products must be determined by those properties which define the possible range of applications for a specific product (for example the salinity in the case of bedding soil, or the pH in the case of particularly demanding crops).

They must be user-oriented, so as to ensure a risk-free application of the compost and avoid any crop failure due to the use of compost. Only in this way will it be possible to convince users of the long-term benefits derived from the regular application of compost.

The new guidelines must answer the following question: how can one distinguish digestate from fresh compost? One way would be to use the process description as a reference: only an anaerobic digestion plant produces digestate. But this creates a problem if the digestate is post-composted. Because this requires to further define when digestate stops being digestate and can start to be called compost. Here too one could simply consider the process description: for example after 4 weeks of post-composting it becomes compost. The problem is that the intensity of the post-composting process is not defined, and here the range of treatment intensity goes from just piling the material up for 4 weeks to turning over the material daily.

The ASCP Guidelines focussed on the characteristics of the process and come up with two essential differences: degradation of wood and ammonium content. Lignin is not degraded during anaerobic digestion, so woody wastes (e.g. straw or hay) are still recognisable after digestion. Besides, during anaerobic digestion consists mainly in a mineralisation of the organic matter, including proteins, and to a much lesser degree in the synthesis of microbial biomass. Therefore, most of the nitrogen will be mineralised to ammonium during digestion, which allows to draw a clear distinction between products where processing emphasis is on the degradation phase and those with the emphasis on the synthesis phase. However, here the "telltale" ammonium can be eliminated in the form of volatile ammonia very simply, just by forced aeration and desiccation, lowering the ammonium content to compost-like values, without the accompanying biological processes.

Therefore, the working group has agreed on the necessity to consider both classes of parameters concomitantly, i.e. the type of organic matter and the content and ratios of mineral nitrogen compounds. But it remains to be seen if it will be possible to find a clear and simple way to formulate

the humus index. If we then combine this with the profile of mineral nitrogen compounds (NH₄, NO₂, NO₃) in the product, it will be possible to distinguish digestate from compost in a relatively simple and practically feasible way.

After having achieved this distinction, we must still define which products can be applied to which use. Simple laboratory analyses and a hands-down approach, will be the key to successfully overcoming this last hurdle in the marketing of products from composting and anaerobic digestion.

Application categories:

- Mulch will not be included as a category, the accompanying explanations will mention that mulch and screen overflow are not considered in the guidelines. General: possible recommendations for by-products. Possible explicit exclusions, on the model of the Austrian Biowaste Ordinance.
- The debate is intense around the similarities and differences between solid digestate and fresh (young) compost, no decision has yet been reached.

Formulating the various qualities

The following table shows the result of the intense first discussions. The columns list the product categories and the lines the application categories that have been agreed on.

approx. market share (2005)	2%	10%	70%	15%	3%
Product groups	Digestate		Compost		
Categories	Solid	Liquid	Fresh	Medium	Mature
Fertiliser	X	X	X	X	X
Soil improver		(X)	(X)	X	X
Agriculture	X	X	X	X	X
Recultivation			(X)	X	X
Horticulture				X	X
Hobby gardening				(X)	X
Growth soils & substrates				(X)	X
Special cultures		(X)	(X)	X	X
Covered cultures				(X)	(X)

X = Application range; (X): restricted use possible / for special purposes / if specific parameters are complied with; empty cells: application not recommended / forbidden.

Conclusions

The overall aim is to attain quality standards for compost and digestate which are uniform throughout Europe. In an environment where borders are opening up more and more, we should all agree to play by the same rules. In our opinion, separate collection is an essential prerequisite for these standards to reach their goal. We also need to submit our products to strict quality criteria, so as to ensure our customers are satisfied. If the same efforts are then applied to the marketing of these well-defined, reliable and high-quality products, it will become simple to answer the question whether the facilities treat waste or process resources. Let us hope that the European biowaste treatment industry will find its way towards a more sustainable and common future.

Acknowledgements

Thank you to the members of the ASCP for their financial support of this project and to all the members of the Quality Guidelines working group for their involvement. Many thanks to Catherine Fischer for translating the text into English.

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Agricultural Humus Management Using High Quality Composts

Stefanie Siebert¹, Bertram Kehres¹

Key words: compost, biowaste, humus reproduction, soil fertilizer, plant nutrition

Abstract

Compost being a „multifunctional product“ has many uses. It is mainly used to improve the soil and as plant nutrition. A balanced humus soil is however the basic requirement for soil fertility and sustainable agriculture. The humus balance of a crop rotation can be calculated according to a concept compiled by the German Agricultural Investigation and Research Association (VDLUFA). The span between the extreme values for humus requirement i.e. humus balance result from the specific local factors that influence the humus needs. The different organic manures are also different in their effectiveness to reproduce humus. This depends firstly on the stability of the organic fractions of the material as well as the application rate which could be given by good practical use. Compost is very suitable for the humus reproduction in soil because it contains a high percentage of stable humus. For soils having insufficient organic substances, humus will have to be added over a longer period of time to regenerate the humus content.

Introduction

Currently about 800 composting plants in Germany treat approx. 8 million tons of biowaste to produce about 4 million tons of compost. A special field for the application of compost is agriculture. Just 3 to 4 % of the arable land in Germany could be served with the actually produced amount of compost. On account of this fact agriculture seems to be a potential customer for the recycling of compost and other secondary raw material fertilisers.

Compost is mainly used to improve the soil (soil fertilizer), as plant nutrition (plant fertilizer) as well as a blending compound in the production of potting soils (top soils, growing media).

Due to intense competition and specializing in the field of agriculture, large areas of agricultural crop lands are increasingly becoming poor in humus. A balanced humus soil is however the basic requirement for soil fertility and sustainable agriculture.

Suitable measures for producing humus are:

- Crop rotation management
- Crop residues management
- Organic fertilization with manure and soil improvers from separate collected biowaste

Causes for the present humus needs are:

- Intensive crop cultivation (monocultures with humus-depleting plants like maize and sugar beet)
- Export of crop residues (straw for material utilization and burning)
- Increased cultivation of renewable „energy plants“(such as corn)

Method

The requirements for good agricultural environmentally sound management are laid down in the German Ordinance on Direct Payments (Direktzahlungen-Verpflichtungenverordnung, DirektZahlVerpflV, 2004). The humus degraded from husbanded areas will have to be put back into the soil. Agricultural farms will therefore have to compile a humus balance record. If the humus balance is negative after a crop rotation, organic substances will have to be added to the soil. The humus balance is calculated on a concept (table 1) developed by the German Agricultural Investigation and Research Association (VDLUFA 2004).

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Table 1: Principle of humus balance

Humus demand	+	Humus reproduction	=	Humus balance
Crop specific changes in humus reserves	+	humus-reproduction of* organic materials	=	Amount of organic materials = humus-nutrition
[kg ha ⁻¹ a ⁻¹ humus-C]		[(kg humus-C) (t substrat) ⁻¹]		[t ha ⁻¹ a ⁻¹ humus-C]

Important for the calculation of the humus balance is the humus demand of the specific crops (fig. 1).

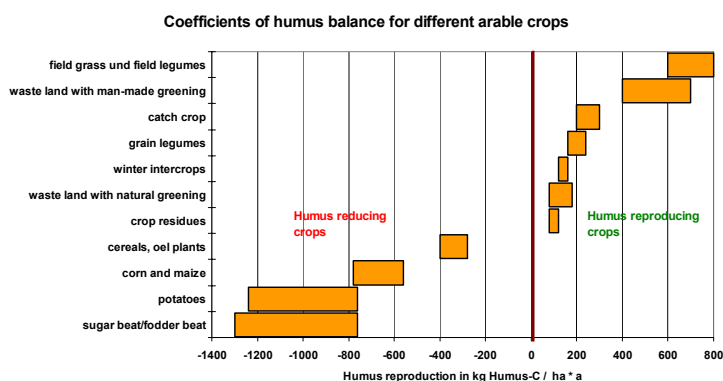


Figure 1: Humus reproduction of arable crops

Source: VDLUFA 2004

In addition the different organic materials are also different in their effectiveness to reproduce humus (table 2). This depends firstly on the stability of the organic fractions of the material as well as the application rate which could be given by good practical use.

Table 2: Humus production efficiency of different fertiliser

	Organic matter ¹⁾	Organic carbon ²⁾	humus-C ³⁾	Humus-C reproduction ⁴⁾
Compost	35 %	20 %	51 %	2,0 t/ha
Manure	75 %	43 %	21 %	0,2 t/ha
Straw	85 %	49 %	21 %	0,7 t/ha
Sugar beet leaves, Green manure	90 %	52 %	14 %	0,6 t/ha

¹⁾ determined by loss of ignition; ²⁾ C organic (LOI/1,72), ³⁾ Percentage of humus reproducable carbon of TOC (reproduction index); ⁴⁾ Humus reproduction by suitable application rates: compost 21 t dm/ha*3a, liquid manure (pig) 2 t dm *2a), straw 7 t dm/ha*a and green manure 8 t dm/ha*a; Source BGK/FAL 2005

Results

Compost is very suitable for this since it contains a high percentage of stable humus. For soils having insufficient organic substances, humus will have to be added over a longer period of time to regenerate the humus content in it. As an example 46 % of the farmland in Saxony shows a negative or strongly negative humusbalance. Since changing the cultivation structure or animal stocks is hardly possible, other humus sources such as composts will have to be used more and more.

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Paper sludge vermicomposts as amendments into the potting media of peppers (*Capsicum annuum* L. var *longum*)

Cristina Lazcano¹, Luis Sampedro², Rogelio Nogales³, Jorge Domínguez¹

Key words: paper-pulp sludge, paper-pulp sludge vermicompost, *Capsicum annuum*, pot amendment, plant growth.

Abstract

Two greenhouse assays were performed in order to evaluate the fertilizing potential of wastewater sludges obtained from paper pulp production where: (i) the raw materials as well as the vermicomposted sludges and (ii) the enriched vermiculites derived from the process were incorporated into the potting media of peppers. Unamended media fertilized with NPK solution were used as controls.

Introduction

Horticultural potting media usually contain substantial amounts of peat moss (*Sphagnum* spp.). Since peat mining endangers non-renewable bog ecosystems, investigations to find alternative substrates for horticultural use are necessary. Solid sludge resulting from the production of paper pulp constitutes a valuable source of organic matter which has been traditionally disposed in a destructive way. Several alternatives for the use of this resource have been proposed. Solid paper pulp sludge could constitute valuable pot amendments for horticulture; yet a pre-treatment of the waste might be necessary to eliminate adverse features. Vermicomposting involves the decomposition of a waste through the joint action of the earthworms and microorganisms (Domínguez, 2004). Previous studies have demonstrated the feasibility of vermicomposting the sludge obtained from paper pulp production either alone or mixed with nitrogen-rich wastes (Elvira et al 1996, 1997); nevertheless it is necessary to assay the fertilizing capacity of the resulting materials and the potential phytotoxicity problems.

Materials and methods

Primary sludge (i) and biological sludge (ii), both resulting from the secondary treatment of the effluents of a Kraft paper-pulp mill (ENCE, Pontevedra, Spain); as well as (iii) a mixture of pig slurry and primary sludge (60: 40% dry weight), were vermicomposted in beds at pilot scale. Beds were constituted by a bottom layer of vermiculite, where 3000 individuals of *Eisenia andrei* (Oligochaeta, Lumbricidae) were inoculated, and a top layer of 100 kg of the waste. The vermicomposts and the enriched vermiculites were collected after 120 days except for the ones derived from the primary sludge which were collected after 240 days.

Two greenhouse assays were carried out using these materials as pot amendments. In the first assay, the sludge and the vermicomposted sludge were added as amendments of the potting media of pepper seedlings at a rate of 4 g dw per pot (equivalent to 100 Kg/Ha) and controls were made with mineral fertilization alone. A commercial vermicompost was included for comparison. In the second assay, pepper seedlings were grown in pots filled with the enriched vermiculite collected from the beds after vermicomposting of primary sludge, biological sludge, and primary sludge + pig slurry; either alone or amended with N-P-K fertilizing solution. Controls were made with fresh vermiculite amended with N-P-K fertilizing solution. Plants were grown until flowering (30% of the buds open) and their growth was evaluated by measuring shoots, leaves and roots biomass, leaf area, leaf number, and tissue content of N, P and K. Data were analyzed using ANOVA and HSD Tukey test. The different growth parameters measured in the plants were subjected to principal component analysis in order to analyze the underlying effect of the treatments on the vegetative growth.

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Results

One component was obtained after PCA analysis which explained 85% of the total variance and summarized the vegetative growth of the plants in both assays (Figure 1). Amendment of the soils with primary sludge and vermicomposted primary sludge reduced the growth of the pepper seedlings as compared to the control. These negative effects were eliminated when primary sludge was mixed with pig slurry. Biological sludge did not produce any negative effect when it was added raw but it enhanced plant growth when it was vermicomposted. Nevertheless the greatest yields were obtained with commercial vermicompost. All the enriched vermiculites (fig 1 b), with or without mineral fertilizer enhanced the growth of peppers as compared to vermiculite alone and even to vermiculite amended with mineral fertilizer. The addition of fertilizer to the enriched vermiculites produced a significant increase of root biomass but not of aerial biomass. All the amendments (raw wastes, vermicomposts, vermiculites and enriched vermiculites) increased the P and K concentration of pepper leaves as compared to the controls, except for the primary sludge that decreased the K content. All the plants showed lower N content than the controls except for those cultivated with biological sludge.

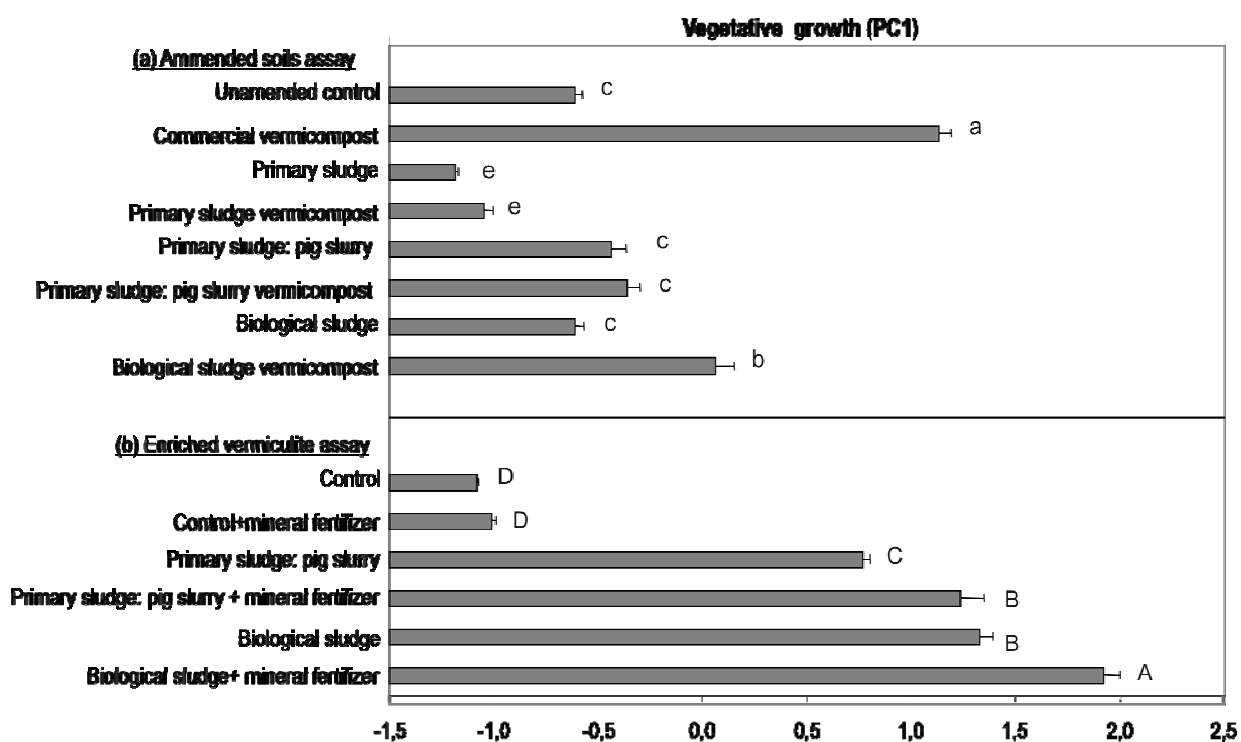


Figure 1: Principal components analysis of the growth parameters (n° of leaves, leaf area, leaf biomass, shoot biomass and root biomass) measured in the plants cultivated in (a) amended soils and (b) enriched vermiculites. Different letters indicate significant differences ($P < 0.05$).

Discussion

Solid paper pulp sludge either raw or composted has shown to have beneficial effects on plant growth in previous studies (Jackson et al., 2000; Bellamy et al., 1995), however suitability of paper sludge as pot amendment strongly depends on the origin and type. While primary sludge cannot be recommended as pot amendment, neither raw or vermicomposted, biological sludge produced similar yields to the control and enhanced growth when it was vermicomposted. Adverse features in the primary sludge may be derived from its low nutrient and high carbon content since they were eliminated after mixing with the waste with pig slurry. The enriched vermiculites produced the highest yields probably due to their physical structure and high nutrient content from the leachates of the vermicomposting process.

Conclusions

Paper pulp sludge vermicomposts and their derived by-products constitute valuable resources as pot amendments which are able to enhance plant growth to a bigger extent than mineral fertilizers and at very low doses. Depending on the initial waste, N deficiencies can be produced; however this could be readily compensated by adding a mineral supplement.

Acknowledgments

Cristina Lazcano is financially supported by a grant from "Fundación La Caixa".

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Waste Fermentation and Sand – no Problem?

Kirsten Schu¹

Anaerobic Digestion, Contraries Removal, NMT-Process, BioFluff, wet mechanical separation

Abstract

Anaerobic digestion of biowaste and organic fraction from municipal solid waste (OFMSW), containing certain amounts of contraries such as sand, gravel, glass and plastics is a rather young technology. The growing experience with industrial scale implementation shows the need for changes in the overall process. A possible solution is shown, using a much improved wet mechanical separation method for waste material, yielding separated inert and organic fractions that can be used f. ex. as building material, RDF or fertilizer. Only the contrary-free process water is used for biogas production.

Introduction

Separation of contraries, such as sand, gravel, glass and plastics, as a pre-treatment for anaerobic digestion of biowaste and the organic fraction of municipal solid waste (OFMSW) is chiefly implemented to protect the plant equipment. This applies mainly to wet anaerobic digestion but recently also to dry anaerobic digestion.

Wet AD (Anaerobic Digestion) processes usually separate contraries by grinding the material and mixing the material with water in a pulper. Part of the contraries is then separated from this suspension by gravity, but the separation is not complete, due to the high viscosity of the suspension. After feeding the suspension into the digester, its viscosity drops quickly because of the bacterial digestion of soluble degradable components. This is the reason for the often experienced sedimentation of sand in the digester as well as for the development of scum layers.

Mechanical separation is more effective in processes without grinding or crushing of the waste material prior to separation. However, due to the low selectivity of the mostly one-stage separation processes the results are also not ideal.

In dry AD plants contraries do usually not interfere with the digestion process itself but are rather impeding dewatering of the digestate and cause similar problems as in wet AD processes.

Development of AD in Germany

The historical overview presented in Figure 1 shows the development of the different AD processes. Until 2004 the total installed capacity of AD plants for the treatment of OFMSW was only 35.000 tons per year in Germany.

The young AD technology is currently booming without being prepared to full extent. Between 2005 and 2006 eleven AD plants for MSW with a total capacity of nearly 1 Million tons per year were commissioned, mostly with unsatisfactory performance.

Advancement of wet mechanical treatment

By developing a new process for the wet mechanical treatment of waste (NMT-process), EcoEnergy could demonstrate that composting as well as anaerobic digestion of suspensions, containing particulate matter, are not technically justifiable in the future.

EcoEnergy could further verify by experiment, that 65 % to 80 % of the biogas production, generated with AD from the total material, would also be yielded using the NMT-process. The process yields low polluted inert fractions that can be used for construction purposes as well as sand-free organic fractions, containing only unpolluted organic matter, separated in fossil and native organic matter.

Due to the very low pollution, the native organic fractions (BioFluff), even from municipal solid waste without separate collection, fulfils the requirements for the German compost application as a high quality fertilizer. The process also reduces the salt content of the BioFluff so that BioFluff meets the specifications for use in coal fired boilers for CO₂-free energy utilisation.

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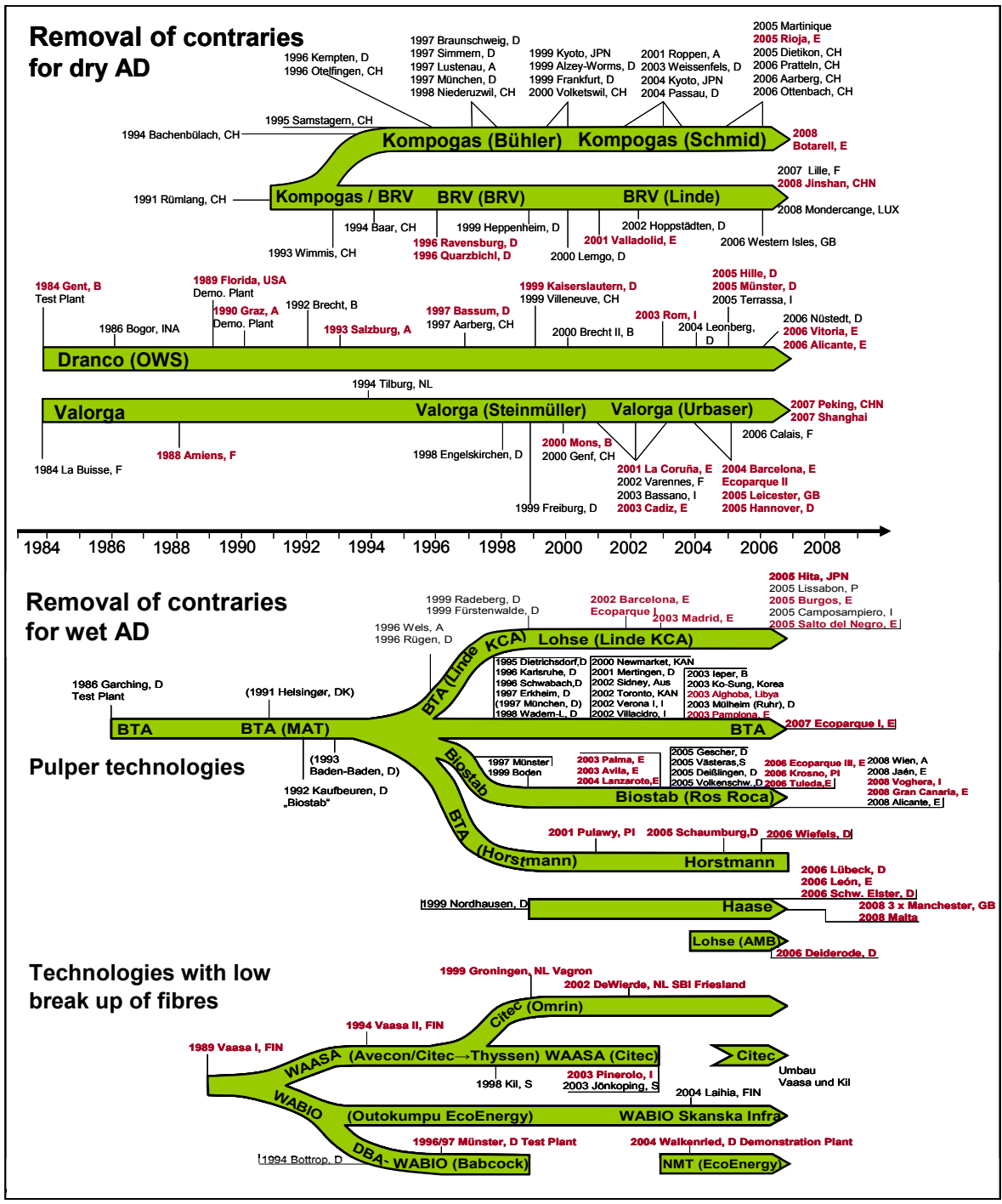


Figure 1: Development of anaerobic digestion (not exhaustive)

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Comparison of the energy recovery and usage of compost from green waste: What is the impact on primary resources?

Martin Kranert¹, Gerold Hafner¹, Ralf Gottschall², Christian Bruns²

Key words: Green waste, energy recovery, compost, primary resources, greenhouse gases

Abstract

Besides the energy recovery, a positive influence on greenhouse gases emissions can be achieved through material recovery and use of green waste – especially as compost and as turf-substitute – although this procedure is currently not supported in Germany. A direct comparison of the two alternatives is not yet available in the current scientific literature. Aim of the research project was to create a data base containing all relevant data about green waste and its products, amongst others soil conditioner, substitute for fertilizer, turf, fuel from biomass etc., with particular regard to carbon dioxide. A comparative balancing of different technical plants shows that the use of compost from green waste as a substitute for turf can save the same amount of CO₂ as the energy recovery of this green waste. The range is between 130 kg up to 1190 kg CO₂-saving per Mg of green waste. In this respect both possibilities seem therefore equal. The research project, already examined by the Universität Stuttgart, in cooperation with Humus and soil cantor (HEKO), Neu-Eichenberg is financed by the EdDE (Entsorgungsverband der Deutschen Entsorgungswirtschaft).

Introduction

The paragraphs §2 and §3 of the Biomass Regulation (2001) allow the use of green waste (from yards and parks) for power generation. The generated electricity is subject to the regulations of EEG (regulation for renewable energy), which means a monetary support up to 13 Cent/kWh.

The aim of the governmental promotion is to substitute primary resources by using renewable products to produce electricity. Unlike energy recovery, material recovery of green waste is currently not supported in Germany.

Humic material in compost, though, assures a partial storage of carbon, achievable even more efficiently when compost substitutes turf (garden earths and substrate). Turf is in fact a primary resource connected to greenhouse gas emissions through the excavation of moors, typical sinks of carbon dioxide.

More arguments for the employment of turf substitutes result from economic as well as from business management considerations. In this context we have to consider the annual need of turf of ca. 10 Mio m³, generating an actual annual import up to ca. 3 Mio. m³ (2003). The German turf reserves are assumed to last another 20 years.

Currently ca. 300.000 m³ compost from green waste are used as turf substitutes. The medium term potential capacity is ca. 1,2-1,8 Mio. m³ p.a., the long term potential capacity is ca. 2,5-3 Mio. m³ p.a.

Evaluations of the two competing alternatives (energy or material use of green waste) are not possible due to the lack of basic data. Although existing studies and reports do not give a clear preference to one of the two alternatives, no governmental support of material usage is available, whereas the energy use of green waste is promoted (ca. 15-40 €/t green waste (Input)).

This current practice needs revision, especially considering the relevance of these benefits.

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Materials and methods

A comparison between the effects of energy recovery and turf substitution quantities of green waste is possible by looking at shredded wood and wood from waste, as well as at the plants for composting and energy recovery. The authors considered different types and qualities of green waste, different technical systems (several types of composting plants and power plants) and the complete process chains containing e.g. the excavation of turf, the collection of green waste, the transports and reloading, the composting plants, the linked processes etc. The data base was enlarged by adding the analysis, as waster content, loss by ignition, calorific value, of samples from green waste (input, screening fractions, processed output). These data served as a basis for the calculation of the scenarios for four different material models: dry, wooden material, mixed green waste with high wooden content, mixed green waste, wet green waste with grass.

Results

The results show that in the best case (wooden material) the CO₂-savings by energy recovery are around 1040 kg/Mg green waste and by turf substitution around 1190 kg/Mg green waste. In the worst case (wet material) the CO₂-savings are around 130 kg/Mg (energetic), respectively 260 kg Mg (turf substitution). For comparison: the substitution effect of wood is around 1080 kg/Mg. The substitution of turf by compost leads to the same CO₂-savings of energy recovery in the case of wooden materials, while for wet mixed green waste the recovery is even more efficient.

Around 25 % to 35 % of input material can be separated as a high calorific value material by screening (20 - 40 mm). The lower calorific value for energy recovery should exceed 10 MJ/kg.

Discussion

Material flow stream control should be used to evaluate the CO₂-savings of the two processing possibilities of green waste, namely the energy recovery and the recycling as compost with substitution of turf; the control would lead to proportional financial incentives and corresponding quality criteria.

Conclusion

Since green waste has capture rates of about 50 %, it should be possible to substitute between 1,1 to 1,3 Mio Mg CO₂/a in Germany by energy recovery and recycling as compost. In order to enhance the quantity of sequestrated CO₂, the collection rate of green waste and of waste from landscaping gardening has to be increased of 50 %. In this case the savings of fossile CO₂ in Germany could reach 2,2 to 2,6 Mio Mg CO₂ and could significantly help to achieve the goals of CO₂-reduction.

Acknowledgments

The authors would like to thank the Entsorgungsgemeinschaft der deutschen Entsorgungswirtschaft (EdDE) for funding the project.

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Potentials and Applicability of Different Biowaste Treatment Methods for Solid Fuel Productions

Bernd Bilitewski¹; Matthias Schirmer¹, Daniel Schingnitz¹, Gaston Hoffmann¹

Key words: thermal treatment, biowaste, chlorine, corrosion

Abstract:

Biological waste treatment is widely accepted as a treatment method for biological waste. In Germany about 12.4 million tons of biowaste are produced and treated with either composting or anaerobic digestion. Composting is a robust practice and state of the art, whereas digestion provides the possibility of energy production from wastes.

Besides these differences, both treatment methods have something in common: they result in a solid output that can be difficult to handle due to the containment of pollutants and/or organic contaminants, hence, quality requirements for use on land sometimes cannot be met.

Therefore, employing the solid output of composting and digestion processes for production of solid fuels should taken into consideration. Aiming at the production of solid fuels from biowaste that meet the requirements for a combustion process, research is done at the Institute of Waste Management and Contaminated Site Treatment (TU Dresden) to ascertain the best way of treating biowaste with respect to the quality of solid fuels.

The compared output materials of different biological treatment methods are compost and solid residues of percolation processes. All materials have to undergo combustions experiments where the flue gases, the ashes and the filter dust are analysed to determine the transfer coefficients for chlorine, as a main problematic component for the combustion process. With the help of transfer coefficients the risk of corrosion and slagging can be assessed. Besides this, chosen key figures are calculated in order to estimate the risk of corrosion.

Introduction:

Using biomass as fuel does not only contribute to climate protection. Moreover, the reduction of carbon dioxide emissions as well as treatment plants for the combustion of biomass have a potential of high temperature corrosion especially due to increased concentrations of chlorine and alkali metals such as sodium and potassium. A common way to estimate the corrosion potential is the calculation of key figures. Furthermore, at the Institute for Waste Management and Contaminated Site Treatment it is possible to determine the risk with the help of combustion tests. On the hand, this is realised with coal and different additives (e.g. sulphur for mobilisation of chlorine species into the flue gas), on the other hand with biomass.

Materials and methods:

The research is being carried out by a high temperature furnace HT-1600G of the Linn High Therm GmbH. An overview of the experimental setup shows figure 1.

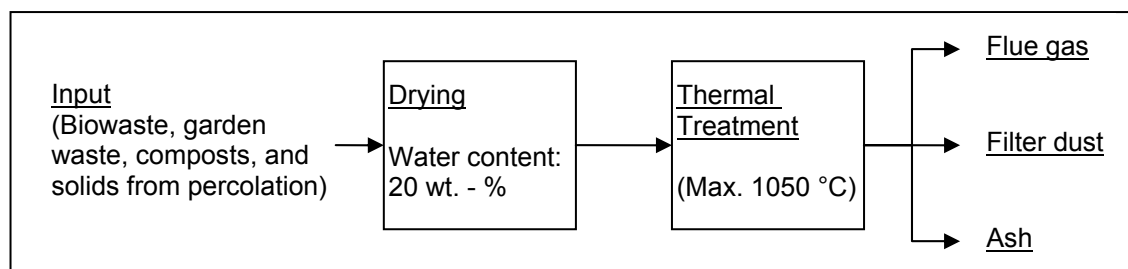


Figure 1: Experimental Setup

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Results and conclusion:

In a preliminary phase, different ratios of light coal, magnesium sulphate, sulfanilic acid and a NaCl/KCl-mixture are burnt and the transfer-coefficients for chlorine into the flue gas, filter dust and ash were calculated. Accordingly, the risk of corrosion decreases by an increased transfer into the flue gas by an ash [Born, 2003]. This effect can be accomplished by an adequate content of sulphur in the fuel which is important for a chemical reaction in the gas phase. HCl is built and removed by the flue gas. If there is not enough sulphur in the fuel alkali chlorides condenses on the surface of the boilers and the built HCl reacts with the boiler-material (Fe) to Fe_2O_3 .

Figure 2 shows the results. By the pre-investigations the influence of sulphur could be shown.

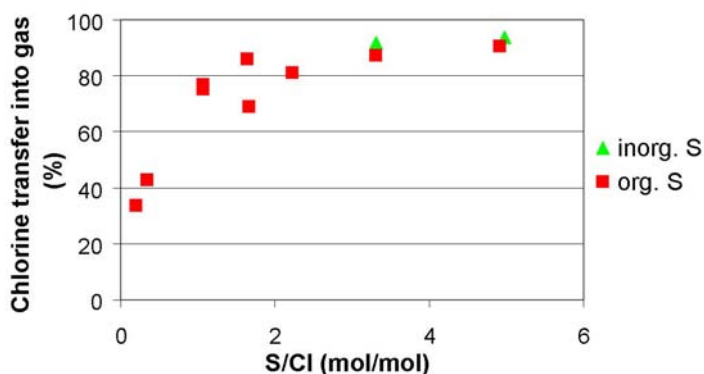


Figure 2: Chlorine transfer into gas after combustion of coal with different additives

During further research, combustion tests are carried out with biowaste, garden waste, solids from different percolations, composts (see also: Comparison of different anaerobic pre-treatment methods for biowaste with regard to potential of biogas production"- Session: Compost and digestate: sustainability, benefits and impacts for the environment and plant production) and the risk of corrosion is calculated. Table 1 shows the accordant key figures for the different biomasses. Consequently, the research has shown is almost no difference of the corrosion risk depending on the biological treatment.

Table 1: Key Figures for estimating the corrosion risk

	$K_{S/Cl}$ [kmol/kmol]	K_{CK} [kmol/kmol]	$K_{A/P}$ [mmol/kg]
Fossil Fuels			
Hard Coal	5,6	0,32	35,7
Light Coal	302,2	0,01	0,8
Biomass			
Gardenwaste	0,60	3,35	156,87
Solids from m. P. of Biowaste	0,93	2,15	93,94
Solids from m. P. of Gardenwaste	0,83	2,40	92,64
Solids from p. P. of Biowaste	1,34	1,50	57,12
Solids from p. P. of Gardenwaste	1,18	1,70	60,93
Compost of Biowaste	1,12	1,79	67,59
Compost of Gardenwaste	0,61	3,29	231,40

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Poster presentations session 2.1

Characterization of the stability and maturity of cattle manure at different stages of the composting process

Maria Gómez-Brandón¹; Cristina Lazcano¹ & Jorge Domínguez¹

Key words: DOC; Mineral N; Microbial biomass; Basal respiration; Phytotoxicity

Abstract

The material collected at the end of the active phase was inadequate to be applied to soil as organic amendment due to its high content of NH_4^+ , its high level of phytotoxicity and the low degree of organic matter stability. After a maturation period of 80 d, the stability of the sample increased; however, 180 d of composting were not sufficient to reduce the phytotoxicity to levels consistent for a safe soil application. Among the various parameters studied, the change in dissolved organic carbon with composting time gave a good indication of stability.

Introduction

The composting process may significantly reduce the environmental problems associated with the management of manures (Carr et al., 1995). The stability and maturity of the compost are essential for its successful application, particularly for composts used in high-value horticultural crops (Wang et al., 2004). The terms stability and maturity are usually used interchangeably to describe the degree of decomposition and transformation of the organic matter in compost (Zmora-Nahum et al., 2005), despite the fact they describe different properties of the composting substrate. Stability is strongly related to the rate of microbial activity in compost, and is evaluated by different respirometric measurements and/or by studying the transformations in the chemical characteristics of compost organic matter. Compost maturity generally refers to the degree of decomposition of phytotoxic organic substances produced during the active composting phase and to the absence of pathogens and viable weed seeds (Wu et al., 2000). Therefore, the two major objectives of this study were (a) to describe the chemical and microbiological changes during the industrial composting of cattle manure and (b) to compare different parameters with respect to their ability to evaluate compost stability and maturity during the industrial composting of cattle manure.

Materials and methods

This study followed the composting process of fresh cattle manure obtained from the agricultural cattle complex "Energía Viva, S.A." in León, Spain. The composting process involved an active phase of 15 d in trenches with forced air, followed by a maturation stage in piles for 270 d. These piles were turned for aeration twice a month and sporadically watered with leachates from the cattle farm. Samples were collected at ten random locations at 15, 80, 180 and 270 d and thoroughly mixed to generate composite samples. The initial fresh cattle manure was also analysed for comparison.

Chemical parameters such as electrical conductivity, pH, total C and N, dissolved organic carbon (DOC) and mineral nitrogen (NH_4^+ and NO_3^-) were analysed. Microbial biomass (microbial biomass C) and its activity (basal respiration) were also determined. The phytotoxicity of the samples was determined following the method of Zucconi and de Bertoldi (1987).

Results

The main chemical and microbiological properties of the samples are shown in Table 1. The active phase was accompanied by a significant increase in electrical conductivity, pH, mineral N and basal respiration, and the maturation period by an increase in electrical conductivity and pH and a decrease in C to N ratio, DOC, mineral N and microbial biomass and activity. A germination index of 87% was recorded after 270 d of maturation (Figure 1). Thus, more than 180 d were needed to overcome the threshold limit of 60% stated by Zucconi and de Bertoldi (1987) to reduce the phytotoxicity to levels consistent for a safe soil application.

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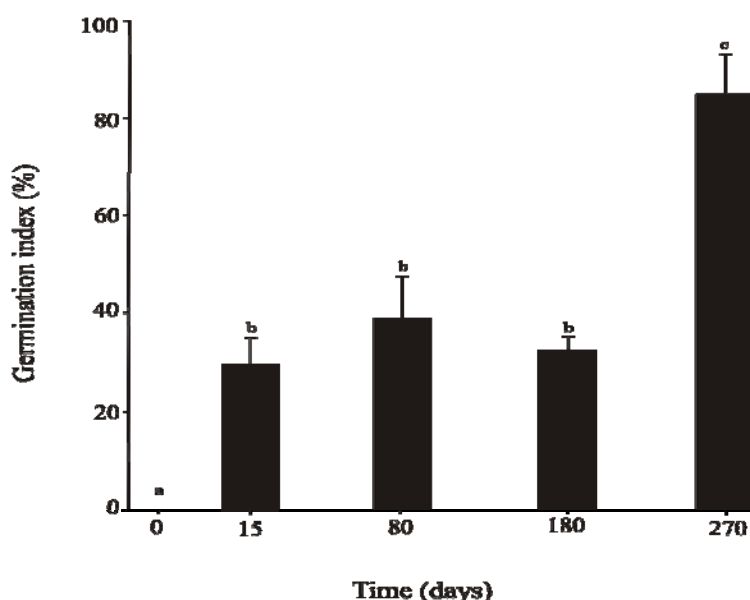


Figure 1: Germination index of the initial cattle manure (t = 0) and the composting material collected at 15, 80, 180 and 270 d.

Tab. 1: Variation of chemical and microbial properties of cattle manure with composting time

	0	15	80	180	270
Electrical conductivity [mS/cm]	1.2	2.2	2.8	2.9	3.0
	(1.1; 1.5)	(1.7; 2.3)	(2.2; 3.2)	(2; 3.7)	(2.2; 3.6)
pH	8.2	8.2	9.2	9.6	9.5
	(8.1; 8.3)	(8.1; 8.9)	(9; 9.4)	(9.5; 9.8)	(8.8; 9.9)
C to N ratio	16.9	17.4	11.5	10.7	10.6
	(15.2; 19.4)	(16.8; 18.6)	(10; 12.1)	(9; 13.1)	(10.2; 10.8)
DOC [mg/kg dw]	4410	7260	3600	3300	1180
	(2290; 6140)	(6400; 8070)	(1800; 4600)	(2600; 4000)	(1110; 1400)
NH₄⁺ [mg/kg dw]	500	1060	300	120	230
	(400; 920)	(1040; 1180)	(200; 400)	(70; 130)	(200; 310)
NO₃⁻ [mg/kg dw]	20	700	20	50	70
	(10; 50)	(510; 850)	(10; 40)	(20.9; 60.8)	(49.7; 80.5)
Microbial biomass C [mg/kg dw]	3710	2630	1600	200	600
	(2010; 8630)	(1820; 3880)	(1000; 2400)	(150; 330)	(500; 800)
Basal respiration [mg CO₂/kg om]	2800	4500	1950	270	600
	(1700; 3200)	(3900; 7200)	(1700; 2200)	(160; 380)	(480; 820)

Discussion

To be a good indicator of compost stability, a parameter should fulfil the following requirements: (a) follow a consistent trend during the composting process; (b) provide reference, critical or threshold values; (c) require relatively rapid and cheap analytical procedures and (d) be easily interpretable. The turning of maturation piles and the sporadic addition of leachates from the cattle farm to these piles influenced several parameters such as electrical conductivity, pH and NO₃⁻ resulting in values that are not typical from the maturation stage. DOC generally contains organic compounds having different susceptibilities to microbial degradation and different phytotoxic properties. For this reason DOC composition may have an important role in determining the stabilization process. In the present study, DOC fulfilled the largest number of requirements; however, this does not mean that this measurement is equally accurate to evaluate the stability of all source materials and full composting facilities.

Conclusions

A maturation period of 80 d was enough to obtain a stable compost as outlined by the reduction in DOC, NH_4^+ and microbial biomass and activity, but not to obtain a mature compost (i.e. with a low degree of phytotoxicity). Determining the change in DOC with composting time seems to be the most suitable measurement to evaluate the stability of the composting material in the present study.

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Comparison of extraction and derivatization methods for the analysis of lipid composition in environmental matrixes with high organic matter content

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Jorge Domínguez¹

Key words: FAMES; Microbial communities; Manure; Compost; Vermicompost

Abstract

In this study the gas chromatography/mass spectrometry analysis of fatty acids in four solid environmental matrixes with high organic matter content was optimized using a multifactor categorical design. Three extraction methods and two derivatization procedures were compared. A modified Bligh & Dyer method in which chloroform: methanol (2:1, v/v) was used as the solvent extraction mixture and the derivatization with TMSH were considered as the best options for the analysis of fatty acid methyl esters in the selected matrixes.

Introduction

The analysis of lipid composition has become an important tool for characterising microbial communities, thereby eliminating the bias inherent in culture-based methods (Tunlid and White, 1992). Fatty acids (FAs) which are the main components of lipids have a polar nature and it is therefore essential to transform them into less polar derivatives called fatty acid methyl esters (FAMES). Most procedures of lipid analysis for the study of microbial communities have been developed for soil. However, the study of microbial communities in other solid matrixes with higher organic contents appears interesting. The biooxidative processes for the treatment of organic wastes as composting and vermicomposting involve complex interactions between the organic residues and the microbial communities. Microorganisms are the main drivers of the biological mechanisms involved in these processes, thus their characterization in terms of their FAME profiles would clearly improve the understanding and development of these processes. Therefore, the aim of the present study was to optimize the extraction of FAs and their derivatization to FAMES in four organic matrixes (pig slurry, cattle manure, compost and vermicompost). We compared three extraction methods - microwave assisted extraction (MAE) and two modifications of the Bligh & Dyer (B & D) method (Bligh & Dyer, 1959) in which chloroform:methanol (2:1, v/v) and chloroform:methanol:phosphate buffer (1:2:0.8, v/v/v) were used as extraction solvent mixtures (B & D_{c:m} and B & D_{c:m:phos})- and two derivatization procedures: alkaline methanolysis and derivatization with trimethylsulfonium hydroxide (TMSH).

Materials and methods

A multivariate strategy of optimization (Statgraphics-Plus, 2003) was carried out in order to assess the influence of the factors type of matrix and extraction and derivatization methods on the analysis of: total FAMES, expressed as the sum of all identified FAMES; the sum of straight chain saturated FAMES (Σ SFAs); the sum of monounsaturated (Σ MUFAs) and the sum of polyunsaturated FAMES (Σ PUFAs). As 18:1 ω 9c and 18:2 ω 6c are considered to be mainly of fungal origin (Frostegard and Bååth, 1996) we included both fungal biomarkers in the analysis. To compare the response obtained by the different combinations of methods, the ratio between the standard peak height of each FAME and the internal standard (19:0) peak height were used.

Results

The modified B & D_{c:m} method provided much higher yields of all variables, except Σ MUFAs, than the other two methods. As an example, the mean plots of Σ MUFAs and Σ PUFAs are shown in Figure 1. When TMSH was used as a derivatization reagent, the yields of FAMES were significantly higher than those obtained by alkaline methanolysis. The mean plots of Σ PUFAs and fungal biomarkers are shown in Fig. 2.

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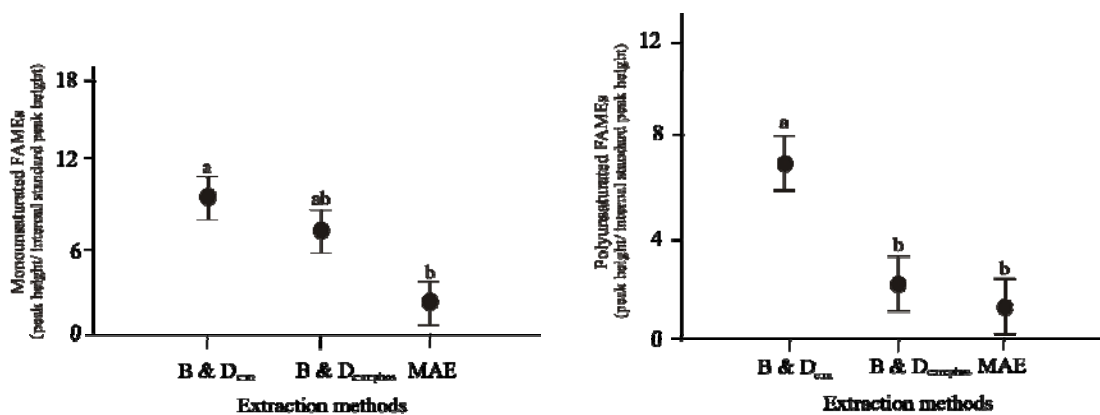


Figure 1: Mean plots of the extraction methods for mono- and polyunsaturated FAMES. Different letters on the error bars indicate significant differences at $P < 0.05$ (Tukey's HSD test).

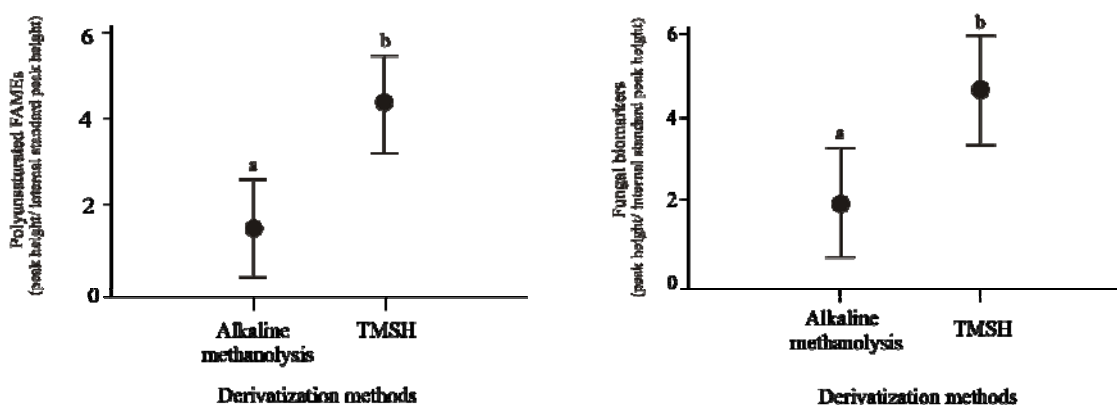


Figure 2: Mean plots of the derivatization methods for polyunsaturated FAMES and fungal biomarkers. Different letters on the error bars indicate significant differences at $P < 0.05$ (Tukey's HSD test).

Discussion

In line with the results obtained, the modified $B & D_{c,m}$ method and derivatization with TMSH are considered as the best options for the analysis of FAMES. The modified $B & D_{c,m}$ method rendered higher yields of FAMES, probably because of the longer incubation time (24 h) involved and the larger volume of extraction solvent mixture used. Moreover, the reduced manual labour required in this technique may result in lower operating costs. One great advantage of TMSH derivatization is that it is a simple and non time-consuming procedure. TMSH has also been reported to be a good choice for methylation of PUFAs because trimethylsulfonium salts decompose at lower temperatures, which thus lessens the degradation/isomerisation side-reactions of PUFAs (Ishida et al., 1999).

Conclusions

It has been shown that the optimized methods of extraction and derivatization can be used to study microbial communities by their FAME content in solid environmental matrixes with high organic matter content. This is extremely useful for comparison of microbial communities in untreated animal wastes as well as in the end products resulting from biological degradation processes (i.e. compost and vermicompost).

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Poster presentations session 2.2

Quality of composted, sewage sludge based soil improvers targeted for landscaping

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Key words: Sewage sludge, soil improver, growing media, quality, maturity, stability, biotest, organic pollutants

Abstract

The quality of composted sewage sludge and corresponding soil improvers were evaluated by chemical and biological methods. The composts and soil improvers differed considerably according to their content of main nutrients, organic contaminants and degree of acute toxicity. In contrast, the phytotoxicity test did not differentiate the studied samples in terms of product quality.

Introduction

Soil improvers and growth substrates based on composted sewage sludge are commonly used for landscaping purposes. Monitoring the quality and environmental effects of soil improvers and growth substrates can enhance their suitability for use in different applications. In addition to chemical analysis, biotests are valuable tools in the risk and quality assessment of soil improvers and growth substrates because they include possible interactions between different chemicals and the complex matrix. In this study, the quality of three different sewage sludge based growth substrates was evaluated by chemical analysis and biotests. In addition to measuring the concentration of main nutrients (N, P and K) and organic contaminants, maturity and ecotoxicity were also analyzed. The organic contaminants studied were AOX, organotin compounds, linear alkylbenzen sulphonates (LAS), bis-2-ethylhexyl phthalate (DEHP), nonylphenol and nonylphenoethoxylates (NP/NPE), PAH, PCB, polychlorinated dibenzodioxin and polychlorinated dibenzofuran (PCDD/PCDF).

Materials and methods

Composted municipal sewage sludge (Compost 1 and 2) and corresponding soil improvers (1 and 2) were collected from two composting plants. In addition, composted fines from the paper machine (Compost 3) and corresponding soil improver (3) were studied. The maturity of the composts was studied by carrying out a carbon dioxide evolution test and determining the nitrate-N and ammonium-N ratio (Itävaara et al., 2006). The concentration of ammonium-N was determined according to EN-13652 and of nitrate-N according to EN standard 10304-2. Eco- and phytotoxicity of the samples was assayed by the kinetic luminescent bacteria test (Lappalainen et al., 1999) and a plant phytotoxicity test based on cress seed germination and root growth (Saadi et al. 2007). The main nutrients (N, P, K) were determined according to EN standards 13650, 13651 and 13652. Organic pollutants were analysed by Lantmännen Analycen Oy.

Results and discussion

According to the results from the carbon dioxide evolution test and nitrate-N/ammonium-N ratio determinations, all the samples were considered mature. Carbon dioxide evolution ranged from 0.3 to 2.5 mg CO₂-C/g VS/d and the nitrate-N/ammonium-N ratio from 1.5 to 148 depending on the sample. The concentration of nutrients (N, P, K) in the samples varied considerably (Table 1). One of the tested soil improvers contained high concentrations of ammonium and nitrate, namely 1.1 g/kg dw (dry weight), and 1.6 g/kg dw, correspondingly. Organic pollutants were detected in some of the soil improvers (Table 2). Soil improvers with municipal sewage sludge as raw material contained AOX, DEHP, PAH and PCB from 210 to 75 mg/kg dw, 21 to 1.2 mg/kg dw, 3.6 to 0.4 mg/kg dw, and 0.08 to 0.01 mg/kg dw, respectively. In addition, TBT (70 µg/kg dw), LAS (190 mg/kg dw) and NP (6 mg/kg ka) were detected in one of the tested soil improvers. The concentration of PCDD/PCDF (I-TEQ) was below the detection limit in all the soil improvers and growth substrates. Overall, the concentrations of organic contaminants in the biosolids were low. Only one of the compost-water slurries, i.e. the sample containing the highest amount of organic contaminants, was toxic in the acute toxicity test

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(Fig. 1a). The EC₅₀_{30min} of hexane extraction varied between 0.4 and 17 g/L. The phytotoxicity test showed no significant decrease in seed germination or root growth in any of the samples (Fig. 1b). Phytotoxicity, which here is expressed as the length of the primary roots of germinated cress seeds compared to a reference, ranged from 89 to 153 % and seed germination from 97 to 100 %.

Tab. 1: Concentration of nutrients (P, K and N) in the composts and soil improvers.

Sample	N* mg/kg dw	P** mg/kg dw	P* mg/kg dw	K** mg/kg dw
Compost 1	2580	27930	29	1930
Compost 2	395	10940	52	3020
Compost 3	154	2680	860	3470
Soil improver 1	600	130	-	150
Soil improver 2	46	66	-	120
Soil improver 3	190	190	-	2300

*watersoluble

** total

Tab. 2: Concentration of organic contaminants in the composts and soil improvers.

Sample	AOX mg/kg dw	TBT mg/kg dw	LAS mg/kg dw	DEHP mg/kg dw	NP mg/kg dw	PAH (16) mg/kg dw	PCB mg/kg dw	PCDD/F ng I-TEQ /kg dw
Compost 1	210	0.07	190	21	6	3.6	0.08	<8.9
Compost 2	75	<0.001	<50	1.2	<0.2	0.4	0.01	<7.6
Compost 3	79	<0.001	<50	0.3	<0.2	0.17	<0.01	<8.1
Soil improver 1	43	<0.001	<50	3.2	3.2	0.73	0.01	nd
Soil improver 2	32	<0.001	<50	0.19	<0.2	1.3	<0.01	nd
Soil improver 3	106	<0.001	<50	<0.1	<0.2	0.13	<0.01	nd

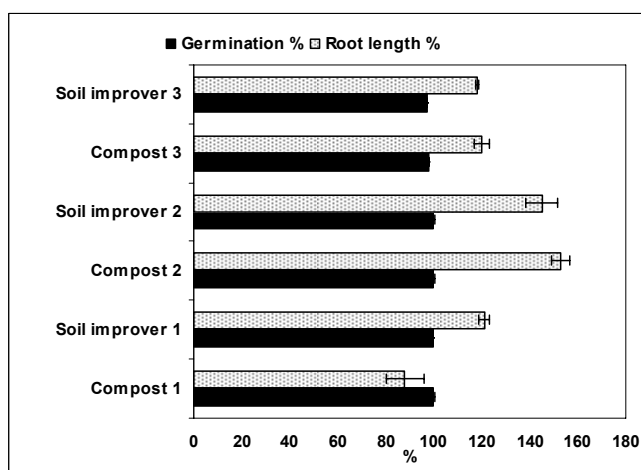
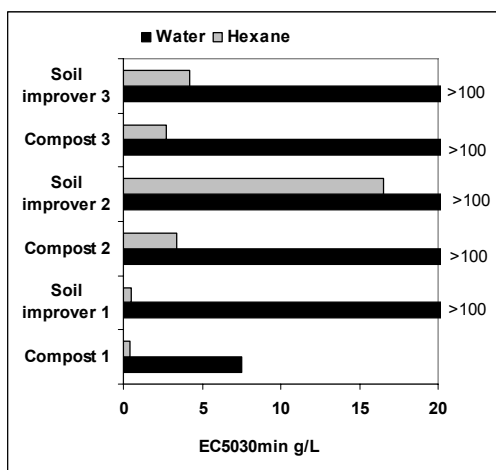


Figure 3a and 1b: a) Acute toxicity (EC₅₀_{30min} g/L) induced by water and hexane extractions of composts and soil improvers was analyzed by the kinetic luminescent bacteria test, and b) the influence of compost and soil improver on the basis of the germination and root length of cress.

Conclusions

The results from this study showed that biotests were useful quality indicators and, together with chemical monitoring, enabled sufficient evaluation of soil improver and growing media quality.

Acknowledgments

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Evolution of exchangeable heavy metals and organic contaminants during composting of greenwaste and sewage sludge

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Key words: sewage sludge, greenwaste, heavy metals, exchangeable, total PAHs, 6-Borneff.

Abstract

The purpose of this experimentation was to study the evolution of a mixture of greenwaste and sewage sludge during co-composting. The mixture was composed of three quarters of greenwaste and a quarter of sewage sludge (18% DM).

Studied parameters was exchangeable heavy metals (extraction with acetic acid-amonia acetate-EDTA) and organic contaminants (total PAHs – 6-Borneff).

Introduction

Presence of Heavy metals and organic contaminants in waste involve problems for treatment and reusing. Concentrations are sometimes such important that using the product is forbidden in agriculture. Sewadge sludge are in particular concerned by this problem. Their use in fertilization could be harmful to the environment, soil and quality of products.

Treatment like co-composting could be a solution. The evolution of materials during the treatment might have a positive effect on these contaminants: reduction of organic contaminants and reduction of solubility for heavy metals. These effects come from the action of micro-organism and variation in physical and chimical characteristics.

Materials and methods

For this experimentation we have mixed sewage sludge (6 metric tons) and green waste (18 metric tons). Sluge was dried until 18% DM. Green waste were crushed before mixing. Materials were disposed in pile during three month with ten turning for aeration.

Sampling was made every 2 weeks and study parameters was dry matter, heavy metals (total and exchangeable) and organic contaminants (total PAHs and 6-Borneff). Extraction for exchangeable heavy metals was made with a mixture of acetic acid-amonia acetate-EDTA.

Results

Heavy Metals

Proportions of exchangeable heavy metals are similar for the two constituents except for Co and Pb whose values are higher in the sludge. Proportions are reduced for Hg and Cr.

Values in the mixture are respectively 84% for Pb, 79% for Cd, 33% for Cu, 28% for Ni, 66% for Zn, 1% for Cr, 16 % for As, 38% for Co and 0% for Hg.

During the treatment, concentration increase. The proportion of exchangeable heavy metals stay nearly constant for Cd, Zn and Cr. We could observe a reduction for Pb, Cu, Ni, As and Co. The values for Hg increase with time (0% in initial mixture for 8% in final product).

Total PAH and 6-Borneff

The initial concentration of total PAHs/6-Borneff in the constituents was 9,69/4,95 mg/kg DM in sludge and 2,00/1,07 mg/kg DM in greenwaste. In the mixture the initial concentration was 6,04/2,78 mg/kg DM.

A reduction of concentration is observed during composting. Final values are 2,71 mg/kg DM for total PAHs and 1,63 mg/kg DM for 6-Borneff. So a reduction of 55% of initial values for total PAHs and 40% for 6-Borneff.

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Discussion

For heavy metals, the effect of co-composting is not clearly proved. Evolution of the exchangeable part is not significant

However this experimentation show that proportions of exchangeable heavy metals are less than 50% of total concentrations for Cu, Cr, Hg, As, Ni and Co in initial mixture and final product. Proportions are inferior to 10% for Hg and Cr. On the other hand biodisponibility is higher than 50% for Pb, Zn and Cd in intitial and final product.

For organic contaminants, the reduction of concentration is clear but initial values was not very high.

Conclusions

If exchangeable proportion of most of heavy metals is reduced we could not foresee the evolution in soil of the insoluble part of heavy metals. Variation in soil condition and action of micro-organism could change their status.

Influence of co-composting on organic contaminants is proved but the amplitute must be checked.

Poster presentations session 3

Application of Municipal Solid Waste Compost Improved Plant Growth in Boron-Toxic and Zinc-Deficient Soils

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Key words: compost, zinc deficiency, boron toxicity, biomass, micronutrients

Abstract

A pot experiment was conducted under greenhouse conditions to study the ameliorative effects of increasing rate of municipal waste compost (0%, 2%, 4%, 8% and 16% [w/w]) and basal NPK fertilizer applications (0%, 33% and 100% of the sufficient basal dose) in two calcareous soils having Zn deficiency (DTPA-Zn: 0.08 mg kg⁻¹) and B toxicity (15 mg B kg⁻¹, hot water extraction) problems. The B-toxic soil had also a low Zn status (DTPA-Zn: 0.10 mg kg⁻¹).

In both soils, increasing rate of compost applications caused up to 5- and 3-fold increases in shoot biomass production at 0% and 33% basal fertilizer rates, respectively. When compost was supplied to plants with sufficient NPK and Zn, shoot biomass production increased only a little, and higher compost rates could not increase shoot dry matter yield. When fertilizer Zn was omitted, Zn from compost amendments restored very significantly the dry matter loss due to Zn deficiency in both soils.

With the addition of compost to Zn deficient and B toxic soils, Zn concentration of wheat leaves showed dramatic increases in all application rates. As judged by the disappearance of Zn deficiency leaf symptoms and corresponding shoot biomass production 2% compost application was found to be sufficient to correct the Zn deficiency problem in both soils.

In Zn-deficient but not B-toxic soil, compost applications resulted in significant increases in shoot B concentration (e.g. from around 10 to 45 mg B kg⁻¹ dry wt). However, in the case of B-toxic soil, with increasing rate of compost, shoot B concentration was decreased by 50% (e.g., from 950 to nearly 400 mg B kg⁻¹ dry wt). These results indicate that compost applications can have multiple benefits on problematic soils as shown in Zn-deficient and B-toxic soils.

Introduction

In Istanbul metropolitan area, nearly 14,000 tons of municipal solid waste (MSW) is collected daily and about 430 t day⁻¹ of MSW is processed for composting at the composting plant of Istanbul Municipality. The produced MSW compost is being used mainly for landscape fertilization purposes, and its role in crop production is being evaluated by greenhouse and field trials. Zinc (Zn) deficiency and boron (B) toxicity are considered to be the two most important micronutrient problems limiting cereal production in the Central Anatolian region, a major wheat growing area of Turkey with 5 million hectares of arable land (Sillanpaa 1982, Cakmak et. al. 1996). Addition of composted organic materials is reported to increase bio-available Zn and at the same time increase the detoxification of free B in soils by complexation of B with different ligands (Bhattacharyya et al., 2006; Yermiyaho et al. 1995). To our knowledge, there is no information in literature on the ameliorative role of MSW on plant growth when added to Zn deficient and B-toxic soils. In the present study, pot experiments have been conducted to investigate the effects of increasing compost and different fertilizer treatments on growth and mineral composition of wheat when grown in Zn-deficient and B-toxic soils.

Materials and methods

Pot experiments were carried out in a greenhouse with climatic control. Plants were grown on two different soils: i) Zn-deficient (DTPA-extractable Zn: 0.08 mg kg⁻¹) and ii) both Zn-deficient and B-toxic soil (DTPA-extractable Zn: 0.10 mg kg⁻¹ and hot water extractable B: 15 mg B kg⁻¹). Basal NPK was applied at 0%, 33%, and 100% of the sufficient rate (i.e. 100% NPK was composed of 200 mg kg⁻¹ N, 100 mg kg⁻¹ P, 175 mg kg⁻¹ K, 20 mg kg⁻¹ S and 2.5 mg kg⁻¹ Fe). For Zn-adequate plants (+Zn) 2 mg kg⁻¹ of fertilizer Zn was applied in the form of ZnSO₄. Municipal waste compost was applied as received at a rate of 0%, 2%, 4%, 8%, and 16% (w/w) for each Zn and NPK level. Initially 15 seeds (*Triticum durum* vc. Kümbet) were sown and at 15 days after planting (DAP) seedlings were thinned to

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10 per pot containing 1.8 kg soil. At 43 DAP plants were harvested for shoot dry matter yield, Zn and B concentration.

Results

With increasing rate of compost applications shoot biomass production was increased by 5-fold at 0% and 3-fold in 33% NPK applications. In both Zn-deficient and B-toxic soils, 8% compost application had restored shoot dry matter yield at 33% NPK to that of 100% NPK (Fig. 1). When basal fertilizer was omitted, increasing compost applications had a higher influence on dry matter production, but compost alone was apparently not enough to improve yield. When supplied with sufficient nutrients (i.e. 100% NPK with +Zn) the increase in shoot biomass production by compost application was less pronounced. However, under Zn deficient conditions, even the lowest compost application rate (i.e. 2%) was enough to restore the maximum dry matter production at 100% NPK for Zn-deficient and 33% NPK for B-toxic soils (Fig. 1). In well agreement with this result, it was shown that addition of compost to Zn deficient and B toxic soils had resulted in dramatic increases in shoot Zn concentration. A compost application rate of as low as 2% was sufficient to correct the Zn deficiency problem in both soils as judged by the disappearance of Zn deficiency leaf symptoms and corresponding shoot biomass production. Irrespective of NPK and Zn fertilizers, shoot Zn concentrations were much higher than the widely accepted critical levels (i.e. 15-25 mg Zn kg⁻¹ dry wt) when compost was applied at the rate of 2% (Fig. 1).

In the Zn-deficient soil, compost applications had resulted in severe increases in shoot B concentration from about 10 to 45 mg B kg⁻¹ dry wt, but the compost-induced B concentrations were lower than the reported critical toxicity levels of 50-400 mg B kg⁻¹ dry wt. Interestingly, in the case of B-toxic soil, increasing rate of compost applications had resulted significant decreases in shoot B concentration from nearly 950 to 400 mg B kg⁻¹ dry wt (Fig. 1).

Discussion

The MSW compost produced by Istanbul Municipality was highly effective to improve plant growth on both Zn-deficient soil and B-toxic soil. It seems that MSW compost is a good Zn source for the Zn-deficient soils. Additional research is needed on to what extent uptake and accumulation of other heavy metals (e.g., Pb, Cd, Hg etc.) is affected. In the case of B-toxic soil, it was interesting to note that B accumulation of plants was very clearly reduced by compost applications while in the soil without B toxicity, compost addition enhanced B concentration of plants. Possibly, application of compost to B-toxic soil inactivated soluble B in the soil solution by complexation as described before (Bhattacharyya et al., 2006; Yermiyaho et al. 1995) while in soil without B-toxicity B existing in the compost contributed to B uptake of plants. It is important to analyse the speciation and binding forms of B in both compost and in B-toxic soil for a better understanding of the differential effects of compost on B accumulation of plants grown in B-toxic and non-toxic soils.

Conclusions

The results presented in this study indicate a double benefit of compost for Zn-deficient and/or B-Toxic soils. Compost was highly effective in alleviating Zn deficiency when applied to a severely Zn deficient and calcareous soil. While correcting Zn deficiency at relatively low rates, it is likely to be useful for remediation of B-toxic calcareous soils.

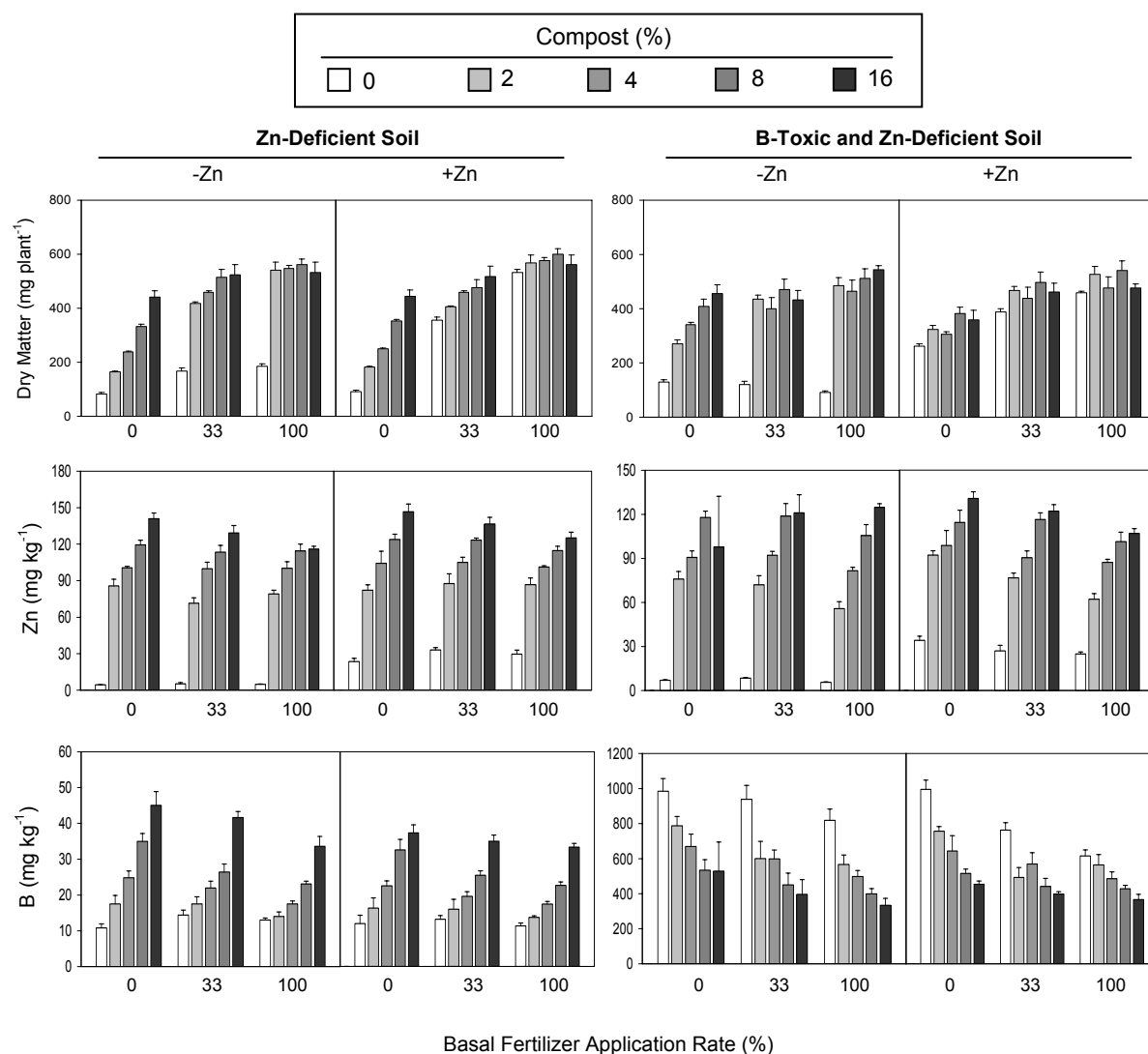


Fig. 1. Effect of increasing municipal waste compost (0%, 2%, 4%, 8% and 16% [w/w]) and basal NPK applications (0%, 33% and 100% of the sufficient basal dose) on shoot dry matter yield, Zn and B concentrations of plants grown in a Zn-deficient soil (0.08 mg kg⁻¹ DTPA-Zn) and a B-toxic and Zn-deficient soil (hot water extractable B: 15 mg B kg⁻¹ and DTPA-Zn: 0.10 mg kg⁻¹).

Acknowledgments

This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) project no. 105 G 148.

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Effects of compost and compost water extract on soil fertility and plant growth

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Key words: Organic agriculture, Soil fertility, Compost, Compost tea, Plant growth.

Abstract

Soil management in organic agriculture aims to improve the soil fertility (SF) even supplying exogenous materials. To evaluate the effects of compost and derived materials on SF and organically cultivated plant growth, also in comparison to commercial organic fertilizers, several experiments were carried out at Mediterranean Agronomic Institute of Bari (MAIB), Apulia, Italy. Compost water extracts also known as compost – tea (CT), were produced and applied to check their utilization as fertilizers. Our investigations aimed to evaluate the influence of compost and CT, in particular on SF and on potato, tomato and broccoli crops. Data obtained show the quality of compost influences positively quantitative and qualitative parameters of crops and soil.

Introduction

The primary goal of organic agriculture (OA) is to optimize the health and productivity of interdependent communities of soil life, plant, animals and people (FAO/WHO, 2001). According to EU Regulation 2092/91 annex II part A, among the strategies that farmers can use for maintaining or increasing soil fertility (SF), exogenous organic matter (OM) can be supplied with composted or not composted material. As a matter of fact, OM is the main tank of organic carbon (OC) in terrestrial ecosystem and is an essential source of nutrients for plant and microbial growth. Through composting, organic materials undergoes a partial mineralization and transformation into humus-like substances (De Bertoldi et al., 1983). The use of compost as soil amendament can improve physical, chemical and biological SF because its characteristics and effects are comparable to those of natural humus in soil. Since 2003 the Mediterranean Agronomic Institute of Bari (MAIB) promoted a research line on the SF management in OA using compost – tea (CT) and compost in comparison to other commercial fertilizers (CF). In particular, three experimental trials were carried out during the last three years.

Materials and methods

A three-year field study, was conducted on three different horticultural crops in short rotation, using a randomized split plot design. During the first year we tested amendment effects on *Solanum tuberosum* L.; in the second year, on *Solanum lycopersicum* Mill and in the third year on *Brassica oleracea* L.. Three different commercial compost (C1, C2 and C3) were applied one for each field trial. In the first year C1, obtained from vegetal residues, was used on potato crop. During the second trial, C2, obtained from pruning, manure and peat, was used on tomato crop. Finally, in the third trial C3, coming from the organic fraction of municipal solid waste and gardening residues, was used on broccoli crop. The crops performances have been investigated also by using of CTs in fertigation. During the first trial, several CTs coming from compost of different origin and extracted with different compost/water ratios (1:5, 1:10, 1:20), were compared. A single c/w ratio have been applied during the second and third year.

CTs were freshly prepared by putting compost in porous bags and steeping the bags in water for two days, under aerobic conditions. To refine the first year results, uniquely dedicated to comparison of several CTs, C2 and C3 were compared with guanito (GU) and bio-rex (BR), respectively, two CF allowed in OA. Soils were characterized by the mean of several physic-chemical and microbial features. Plant samples were also taken, in each trial from each treatment, for measuring quantitative and qualitative parameters, in order to assess the effects on plant growth.

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Results

During the first year, the highest yield was obtained by using the most diluted CT (1:20) coming from the highest quality compost (on farm compost, made of manure and green residues). During the second trial, C2 and GU as well CT2 revealed significant and similar positive effects on yield, in comparison to control. Moreover CT2 increased barries vitamin C content (Fig. 1). Research on broccoli showed the best agronomical results were obtained by using of BR alone and BR combined with C3, even if the application of BR alone revealed the highest nitrate accumulation. Finally, the compost application seems to enhance the soil bacteria community, while the fungal community is positively affected by CTs (Fig. 2).

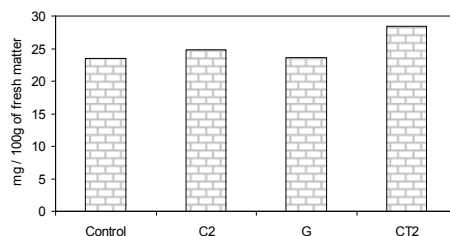


Figure 1: Vitamin C average contents for tomato.

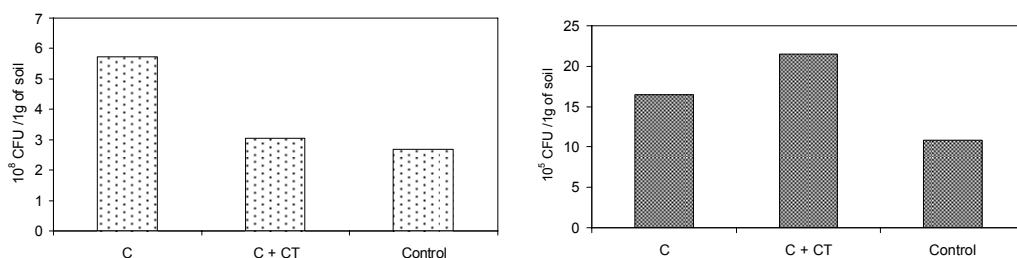


Figure 2: Effect of different treatments on number of soil bacteria (on left) and on number of soil fungi.

Discussion

The CT quality positively influenced the first year results. The CT coming from the high quality compost (on farm compost made of manure and green residues) showed the best performances, even if used with the highest dilution. Data of the 2nd and 3rd year, showed that the slower mineralization of the compost in comparison to CF supplied effectively nutrients to crops, without the problems of nitrate accumulation. Furthermore, the positive effect of compost and CT on soil microbial communities, can be connected to the direct contribution of nutrients and/or to the best life conditions.

Conclusions

All data suggest that the quality of compost influences positively quantitative and qualitative parameters of crops and soil. Further studies are needed to improve knowledge about compost and CT effects.

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'Organic' and 'nitrogen' values of organic amendments and fertilizers

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Key words: C/N ratio, Lignin/N ratio, BSI/N ratio, N mineralization

Abstract

The proportion of total organic N in organic products added to soil that may contribute to N nutrition of crops is traditionally related to their C/N ratio. However, the mineralization and reorganization of organic C and N also depend on biochemical components such as lignin, crude fibres, hemicellulose, or soluble fractions that make up their biological stability (BSI). We thus compared the C/N, lignin/N, and BSI/N ratios as indexes of potential N mineralization from organic products. The BSI/N ratio effectively predicted mineralized N as a fraction of total N. Hence, BSI provided the necessary information to compute labile and recalcitrant pools of C and N for modelling purposes.

Introduction

The C and N cycles are biologically linked and commonly represented as the C/N ratio. Consequently, organic products are typically characterized by their total C and N contents. Simple two-compartment models, such as the ICBM (Andrén and Kätterer 1997) also require distinct pools of C with respect to the mineralization of the young and old fractions of soil organic matter. The C and N pools are thus partitioned into a recalcitrant fraction and its complement, the labile fraction. The isohumic coefficient, k_1 , is defined as the fraction of added C that remains recalcitrant and is usually determined from long term experiments. As a surrogate for k_1 , a biological stability index (BSI) can be computed from relationships between biochemical fractions and stable organic C extrapolated from 6-month incubation data (Linières and Djakovitch 1993). The objective of this paper was to derive recalcitrant and labile C and N pools of organic fertilizers and amendments from BSI as C index and either the C/N or the BSI-to-N ratio as index of N mineralization of organic products added to soil.

Materials and methods

Eight composts made of plant residues, county organic residues, paper sludge compost, undefined manure, shrimp and peat, sheep manure, chicken manure or cow manure, as well as four manure materials (swine sludge, hen manure, granulated chicken manure, and granulated mix of chicken litter and swine sludge) were analyzed for soluble (SOL), hemicellulose (HEM), and lignin+cutin (LIC) fractions using a modified van Soest method (AFNOR 2005) adapted to an ANKOM^{200/220} apparatus. Crude fibre (CF) fraction was obtained using the Wende procedure (AFNOR 2005). Loss on ignition was determined by ashing at 550°C for 16 h. All fractions were expressed on an organic matter basis (i.e. loss on ignition). Total C and N were determined by combustion (Leco CNS 2000). BSI was computed as computed from Linières and Djakovitch (1993):

$$BSI = 2.112 - 2.009SOL - 2.378HEM - 2.216CF + 0.840LIC \quad (1)$$

Potentially mineralizable N (N_0) was modelled from cumulative mineral N production over 26 wk of incubation in a sandy soil. SPSS version 13.0 was used for curve fitting.

Results and discussion

Hen manure showed a negative BSI value (-0.15) and a compost made of chicken manure showed a BSI value exceeding 1 (1.125) as a result of computing Eq. 1 where LIC content was either very small or very high. After constraining BSI values within a scale between 0 and 1, the range of BSI values was between 0.01 and 0.78, respectively. Labile C was computed as the complement of rescaled BSI, hence ranging between 0.22 and 0.99. The N_0 as labile organic N was more strongly related to the BSI/N ratio than the C/N ratio (Fig. 1). The BSI and BSI/N ratio could thus be useful to run two-compartment C and N models.

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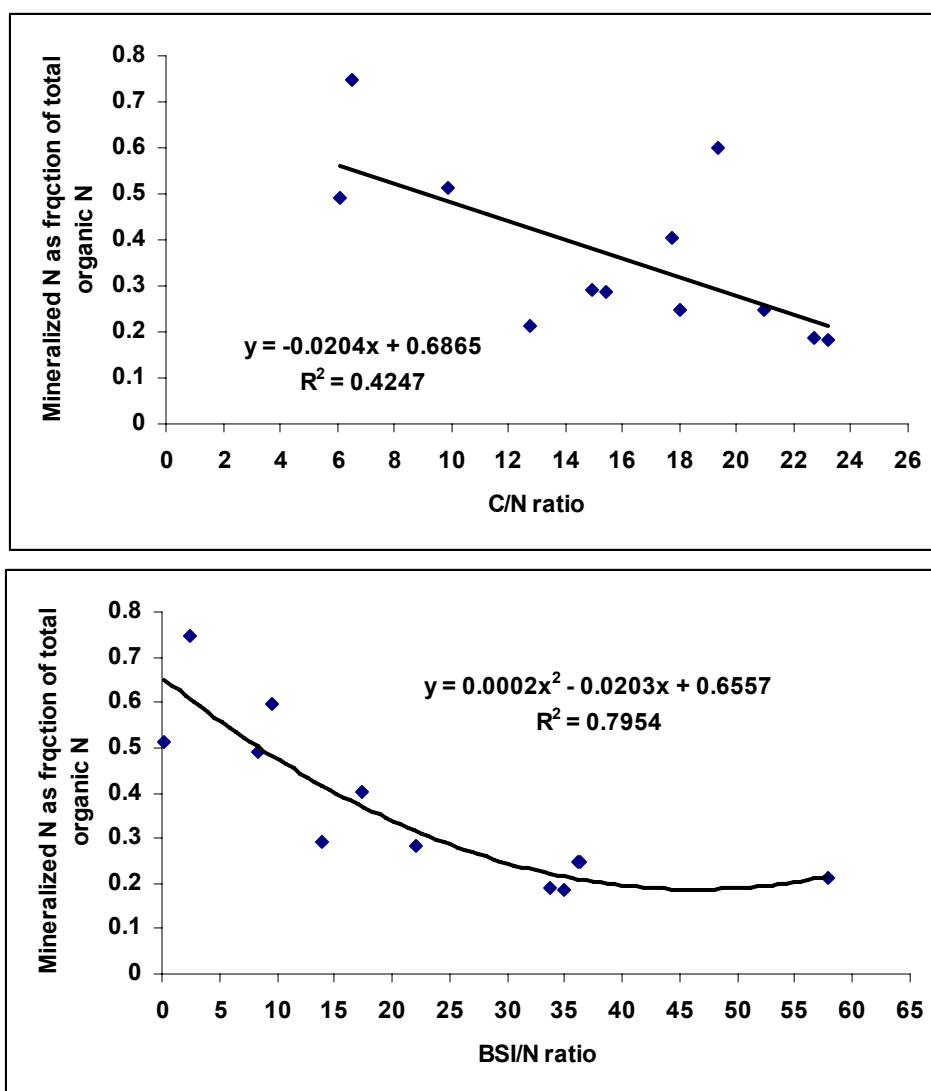


Fig. 1. Relationships between the C/N and BSI/N ratios and mineralized N after 26 wk of incubation of 12 organic products in a sandy soil.

Conclusions

Organic products added to soil contain recalcitrant and labile C and N fractions that can be assessed by laboratory analyses. To quantify these C and N pools, it is necessary to quantify total C and N as well as BSI computed from SOL, HEM, crude fibre, and LIC.

Acknowledgments

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Poster presentations session 4.1

The fertilizing impacts of vermicompost on growth and yield characteristics of German chamomile (*Matricaria recutita* L.)

Parastoo Hoseinzadeh¹, Abdollah Hatamzadeh², Ershad Tavakol³.

Key words: Vermicompost, Soil fertility, German Chamomile, Oil yield, qualitative-quantitative characteristics

Abstract

Organic wastes can be broken down and fragmented rapidly by earthworm, resulting in a stable nontoxic material with appropriate structure which has potentially high economic value as a soil conditioner for plant growth. In order to dedicate the best quantity of vermicompost application as an only plant nutrient source on agricultural and medicinal characteristics of German Chamomile, a field experiment was conducted in the autumn of 2005. The results represented different vermicompost levels (0, 4, 8, 12 & 18 t ha⁻¹) derived from cattle manure and crop residues, improved and enhanced plant growth, plant height, number of shoots and flower accumulative dry matter through increasing fertilization levels; as a result, the implementation of 16 t h⁻¹ had the most significant effect on the mentioned characteristics. Oil yield were increased by 0.69 to 4.23 percent as compared with control (non-fertilized). But there was no significant difference between 12 t h⁻¹ and 16 t h⁻¹ treatments on flower accumulative fresh and dry matter (g), oil yield (kg h⁻¹) and contents (%). To indicate the correlation between improving agricultural and medicinal characteristics of German Chamomile with soil fertilization, the content of N, P and K were evaluated in soil and plant aerial parts of each plot. Consequently, providing plant essential macro elements via application of vermicompost fertilizer lead to significant plant growth and increase plant yield.

Introduction

Beneficial effects of vermicompost on biological, chemical and physical properties of soils due to the nutrient supply and organic matter are well documented (e.g. Fricke and Vogtmann, 1994; Giusuiai et al., 1995; Agassi et al., 1998). Soils in many areas of Iran are generally characterized by small content of organic matter, which greatly contributes to their limited fertility and production levels. Iran is one of the Asian countries, in which particular attention has been devoted to research on medicinal plants in all aspects; especially in organic cultivation to raise producing healthy plants and restore soil composition. With this changing trend, it is necessary to study on using the organic manure from available organic matter sources to approach the high level of production which is currently obtained from intensive use of chemical fertilizers. Referring to the mentioned situation, vermicompost among the most abundant organic waste could be advantageously used for this object. It has already been established as a recommended fertilizer for improving the productivity of several medicinal and aromatic plants, as Amaryllis (El-Ashry et al., 1995), Peppermint (O'Brien and Barker, 1996) and *Tagetes erecta* (Khalil et al., 2002). German chamomile (*Matricaria recutita* L.), can be considered a star among medicinal species and it belongs to the most popular medicinal plants, whose multi-therapeutic, cosmetic, and nutritional values have been established through years of traditional and scientific applications (Mann and Staba, 1986). Although German chamomile can grow on both fertile and poor soil but soil fertility definitely affects the plant qualitative and quantitative characteristics.

Materials and methods

The field study was performed at Tehran University research center, Karaj, in 20 plots with dimensions of 20×30 cm² in randomized-block design with four replications, during 2005-2006. Early in September, soil samples were taken before sowing. Samples for soil fertility control were taken with agrochemical bore from the 0-30 cm depth. The soil measured parameters were; Soil pH, Ec, OM, Bulk density, Total N, Available K₂O, P₂O₅. The experiment treatments were different vermicompost levels (0, 4, 8, 12 & 18 t ha⁻¹) derived from the composition of cattle manure and crop residues. Vermicompost was applied before sowing the seeds and incorporated into the top 15 cm of the bed in the plots. Seeds were sown in late autumn and the soil surface was subsequently firmed by rolling to assure good seed-soil contact. Weed was controlled by hand and plots were irrigated at seven day intervals to prevent any water deficit. During the flowering period, the plant height, flower diameter,

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and anetha fresh and dry weight were measured during three separate harvests using a random selection of plants within each plot. Flower heads were hand harvested at the medium stage of their development and dried at 38° C for 72 h. To extract the essential oil by water distillation, the dried flowers were placed in the flask containing water and the unit is carried to boiling. The vapor mixture of water–oil produced in the flask then passes to the condenser, where it is condensed. The oil is recovered after decantation. The essential oils obtained by both extractions were analyzed by gas chromatography (GC) and gas chromatography–mass spectrometry (GC–MS) under previously established operating conditions. The essential oil yield was estimated according to the dried flowers by using the following equation: $R_{HE} = m_{HE} / m_S \times 100$; m_{HE} = essential oil mass (g), m_S = dried flower matter mass (g) and R_{HE} = essential oil yield (%). In addition, to dedicate the relationship between plant macro elements absorption and soil fertility, plant aerial parts of each plot were decomposed. The analysis of variance was used to test for significance and means were separated using Duncan's New Multiple Range Test at the five percent probability level.

Results

The results represented that vermicompost application affected all measured soil properties of the soil and plant morphological characteristics and oil yield. On one hand, the implementation of the fifth treatment (16 t h⁻¹) had the most significant effects on all evaluated characters compared with other treatments. The highest flower fresh weight per plot (192.64 g), flower dry matter per plot (21.25 g), number of flowers per plant (80), flower diameter (3cm), plant height in flowering stage (41 cm), oil content in 100 g of dried flowers (4.55%), yield production (241.93 kg h⁻¹), chamazulene percentage (17.53%), trans-beta farnesene percentage (4.08%) and alfa-bisabololoxide-B percentage (35.53%) were obtained from the fifth treatment (16 t h⁻¹). Furthermore application of this treatment increased NPK content in chamomile foliage and improved physicochemical properties of soil. On the other hand there were no significant differences between fourth (12 t h⁻¹) and fifth treatments on flower fresh weight per plot, flower dry matter per plot, essential oil content, yield production and oil compositions. Extracted oil content (%) from control plots (T₀) was 0.69%, whereas vermicompost treatments produced more oil by considering the level of application. The maximum values of oil content (4.23% and 3.85%) were obtained as a result of the fifth and fourth treatment (16 and 12 t h⁻¹) respectively.

Discussion

Considering the results, it is noticed that growth characters of German chamomile were increased with application of vermicompost treatments. These results may be attributed to the role of macro and micro-nutrients provided by vermicompost as well as the improved soil conditions due to vermicompost application, which conducted to stimulate metabolic processes and encourage growth, synthesis and accumulation of more metabolites in plant tissues. Several investigators mentioned similar results on different plants such as O'Brien and Barker (1996) on peppermint, Herrera et al. (1997) on horehound, thyme and angelica plants as those of El-Desuki et al. (2001) on sweet fennel, Khalil et al. Generally, it has been observed that there is a positive correlation among soil fertility, essential oil quality and quantity of German chamomile.

Conclusions

It is concluded that vermicompost application in crop production has a positive effect on the yield of German chamomile and its main substance content. According to the results, considering the economic expenses, application of 12 t h⁻¹ vermicompost is the optimum quantity to produce German chamomile and conducted to improve soil properties at the selected region.

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Evaluation of the effect of compost as soil bed for cucumber seedling production

Mohammad Kamalpour¹, Bahram Tafaghodinia²

Key words: compost, damping-off, disease, cucumber, organic

Abstract

Due to economic importance of chemical fertilizer and problems of their application in cucumber production, using a suitable alternative control method is inevitable. To achieve this aim we eliminate the fertilizer and pesticide usage by compost. A project in a general factorial design for 3 factors (soil bed, soak seed, planting pot) was conducted including eight treatments (compost, peat moss, soil solarized, peat moss + compost, soak seed, no soak seed, transparent pot and dark pot) in 3 replicates in shahriar area during 2006. The stem thickness, leaf surface and percentage of Damping-off were recording every 5 days before appearance of fifth leaf. The highest stem thickness and leaf area were in compost treatment. Also pots treated with peat moss were infested 75% but there were not any infection in other treatments.

Introduction

Organic agriculture refers to the operation which the aim of this is decreasing the unnatural saving usage, in this method we eliminate the chemical drugs, poison and fertilizer usage. The problem of disease in greenhouse crop is severe, and their control by conventional methods is uneconomical and it is a threat to human safety. Also the production of cucumber is more than 1500 million tons in Iran. So produce of Cucumber free of chemical fertilizer and pesticide is very important.

Then we should look for alternative methods to replace the synthetic chemicals such as compost which is cheaper in comparison to other method and very safe with no harms.

Materials and methods

A project in a general factorial design for 3 factors (soil bed, soak seed, planting pot) was conducted including eight treatments (compost, peat moss, soil solarized, peat moss + compost, Soak seed, no soak seed, transparent pot and dark pot) in 3 replicates in shahriar area during 2006.

We handled our experiment in ordinary greenhouse at Iranian Research Organization for Science & Technology (IROST) which is located almost in southwest of Tehran. Measuring responses were including: stem thickness, leaf surface and percentage of Damping-off infection. Experiments were conducted in greenhouse under 35±5 degree centigrade and 60±5 Relative humidity. Responses were recording every 5 days before appearance of fifth leaf (35 Days). We used a caliper with ±0/1mm.

Results

The result revealed that the highest stem thickness (0.37cm) and leaf area (20.14cm) were in compost treatment (with significant difference) and there were no significant difference among the other factors.

Analyses of variance indicate that Damping-off infection was significantly difference among soil bed treatments. Pots treated with peat moss were infested 75% but there were not any infestation in other treatment. This observation showed that beneficial microorganisms in compost could control the plant disease in infested soil bed even the pots treated with mixture of compost and peat moss.

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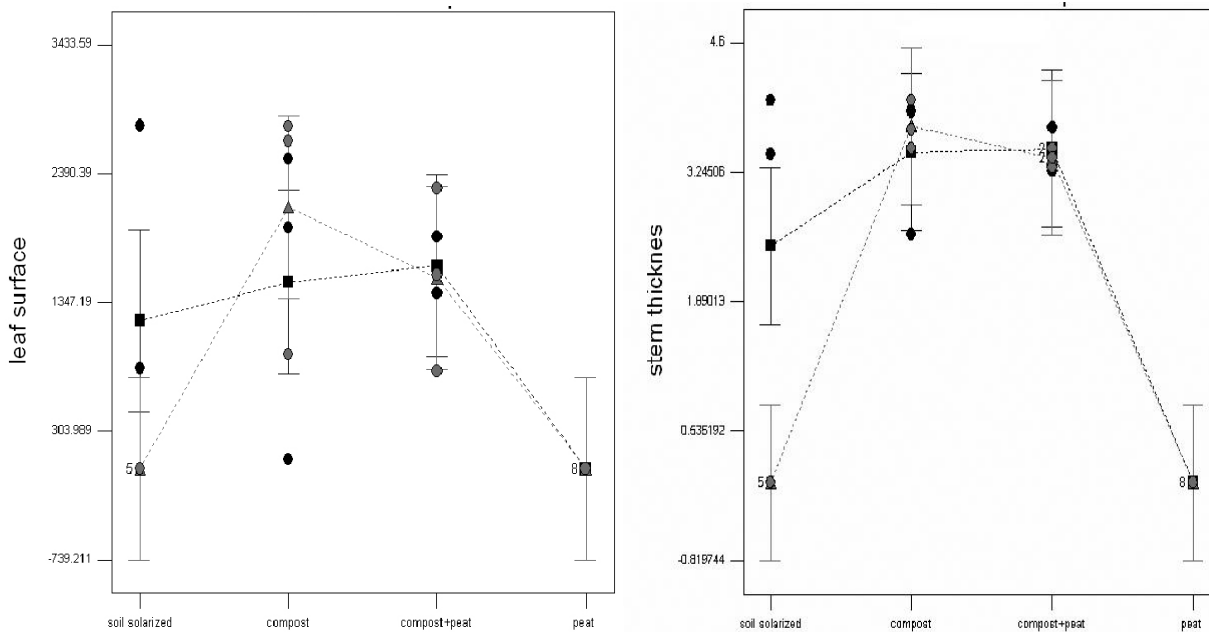


Figure 1: Influence of compost on mean leaf surface and stem thickness cucumber seedling in four treatments (soil solarized, compost, compost+peat, peat).

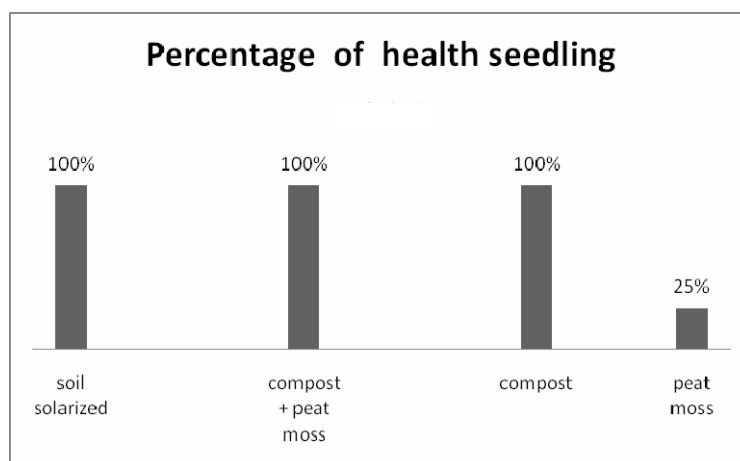


Figure 2: presence of damping-off on cucumber seedling in pots treated with peat moss and percentage of health seedling

Conclusions

The result revealed that if compost is used as soil bed of seedling can produce resistance seedling and control plant disease such as Damping-off. Therefore in an integrated pest management program of organic cucumber production, application of compost as seedling soil bed is recommended.

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Enhancement of pine (*Pinus pinaster*) seed germination by vermicompost and the role of plant genotype

Cristina Lazcano¹, Luis Sampedro², Rafael Zas², Jorge Domínguez¹

Key words: vermicompost, *Pinus pinaster*, seed germination, plant genotype, amendment x plant genotype interaction.

Abstract

The use of organic fertilizers such as vermicompost has shown to enhance germination and growth of several plant species. Nevertheless effects might vary depending on plant genotype. Here we investigated how the incorporation of vermicompost can affect seed germination in six progenies of pine trees.

Introduction

The use of organic fertilizers such as vermicompost might be considered in forest nursery as a mean to reduce expenses and adopt more environmentally-friendly practices. Genetic improvement programs select genotypes that best meet the requirements for a good adaptation to the environment and optimal yields; nevertheless, given the phenotypic plasticity of the species, their growth and field performance might vary depending on the environment and breeding practices. Several studies have demonstrated that vermicompost can improve germination and enhance growth in some plant species and at very low doses (Edwards et al., 2004; Zaller, 2007); nevertheless, the effects of vermicompost have been described mainly on horticultural and ornamental plants and to a lower extent in forestry species. Besides, vermicompost effects might vary between genotypes of the same species. We therefore investigated the effect of vermicompost, on the germination and early development of six progenies of *Pinus pinaster*.

Materials and methods

Pine seeds from six open-pollinated *P. pinaster* families, selected for superior growth, stem form and branch characteristics, were collected from an experimental orchard in Sergude (Galicia, NW Spain). Eight seeds belonging to the same family were sown in 500 ml pots, filled with perlite and a superficial layer of 3 cm of sand, where the treatments were applied. Treatments consisted in: (i) solid vermicompost incorporated into the sand layer (1:1, v:v), (ii) vermicompost tea administrated once a week. Controls were made with no vermicompost addition. Seedling development was divided in four early developmental stages comprising from emergence to the appearance of the second set of needles and a number (1-4) was assigned to each of them. Seed germination, seedling growth at stage 4 and ontogenic development were evaluated. Data were analyzed using ANOVA with genotype and treatment as main factors and seed weight was introduced as a covariable. Significant differences were further analysed with Tukey HSD test.

Results

As expected, both germination and early development of the seedlings were under a strong genetic control. In addition, the amendment with organic products significantly affected most of the parameters studied. Both solid and liquid vermicompost showed to be suitable amendments for the potting media of pines. The percentage of final germination was increased by vermicompost tea addition (Treatment: $F_{2,61} = 5.1171$, $P < 0.01$; figure 1) and the seeds that germinated with vermicompost tea matured faster than those germinated in vermicompost (Treatment: $F_{2,61} = 4.197$, $P < 0.05$; figure 1). The seedlings amended with vermicompost and the ones with vermicompost tea showed significantly lower root biomass than the controls (Treatment: $F_{2,61} = 5.534$, $P < 0.05$). However the treatment factor did not affect the aerial biomass, and the smaller root biomass observed in those treatments did not generated nutrient deficiencies, since nitrogen concentration in the seedlings amended with vermicompost products were significantly greater than in the control plants (Treatment: $F_{2,61} = 7.326$, $P < 0.01$). Most of the genotype x treatment interactions were not significant, showing that the vermicompost effects were similar through the six families assayed.

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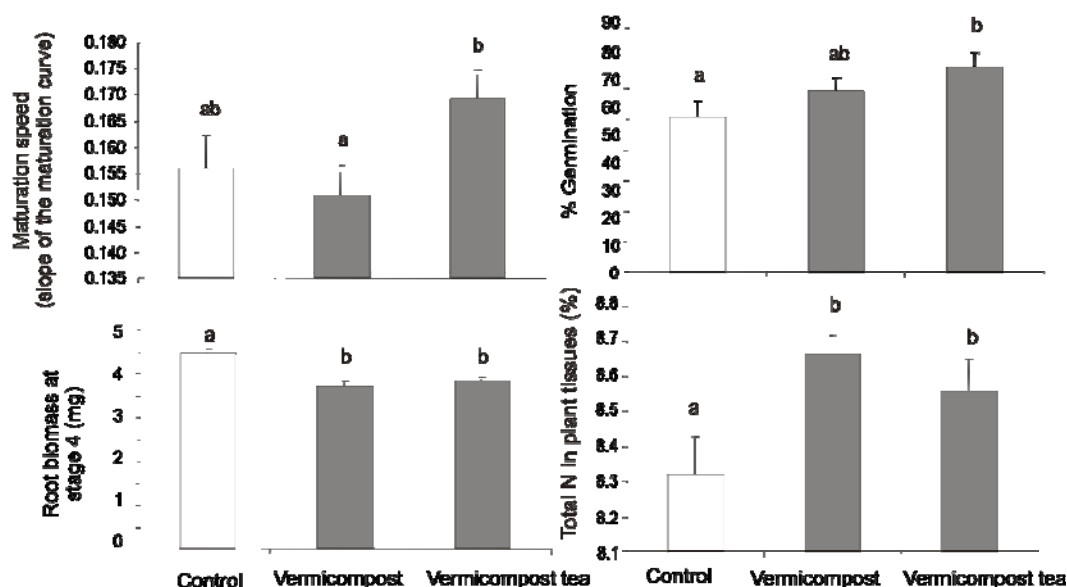


Figure 1: Maturation speed, % of final germination, root biomass at stage 4 and total N in plant tissue, of the pine seedlings germinated in sand (control), sand+ vermicompost (vermicompost), and sand+ vermicompost tea (vermicompost tea). Means \pm standard error. Different letters indicate significant differences at $P < 0.05$.

Discussion

Although germination is an internally regulated process influenced mainly by seed genotype, external factors such as light period, temperature, moisture, and application of certain chemical compounds can also alter this process, either through promotion or inhibition. Generally, the results observed here show that the incorporation of solid vermicompost in the growing media of pine is possible without detrimentally affecting germination of the seeds; moreover, vermicompost can promote germination when it is applied as a tea independently of seed genotype. Incorporation of vermicompost may improve physical properties of the pots such as moisture retention and aeration when compared to sand alone. Nevertheless, percentage of final germination was increased with liquid vermicompost showing that other factors rather than physical were responsible for higher germination. Growth was also influenced by the treatments applied independently of the genotype and the seeds germinated with vermicompost tea grew faster than the ones germinated in vermicompost or the control medium. Furthermore, seedling biomass, which was under strong genetic control, was decreased by vermicompost addition (either solid or liquid) due to the decrease of root biomass. However, this decrease was not attributable to a nutrient deficit, since seedlings with vermicompost and vermicompost tea had significantly higher N content, or to the physical features of the growing media, since the effects were observed both in solid and liquid vermicompost. Probably the higher nutrient availability in the vermicompost treatments made unnecessary the root development observed in the control.

Conclusions

Vermicompost, either solid or liquid, seemed to be an adequate amendment for pine seed germination increasing the number of seeds germinated and accelerating seedling development. The higher nutrient content seems to be responsible for decreased growth and faster maturation, but other mechanisms which still need to be investigated, might be involved in the promotion of germination.

Acknowledgments

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Vermicompost as potting amendment for the growth of different progenies of pine seedlings (*Pinus pinaster*)

Cristina Lazcano¹, Luis Sampedro², Rafael Zas², Jorge Domínguez¹

Key words: Vermicompost, forest nursery, *Pinus pinaster*, plant growth, amendment x plant genotype interaction.

Abstract

We investigated the effect of vermicompost on pine seedling growth independently of nutrient mediated effects, and the influence of plant genotype on the response to the addition to this kind of organic amendment. Vermicompost was incorporated, either solid or liquid, at several doses into the potting media of five selected pine progenies. Growth and maturation of the seedlings were evaluated 20 weeks after sowing.

Introduction

Conventional forestry breeding entails the use of big amounts of mineral fertilizers and peat. Environmentally-friendly alternatives contemplate the incorporation of organic fertilizers as a partial substitution of peat, a non-renewable resource, and substitute of the expensive mineral fertilizers. Several benefits of the use of vermicomposts as organic amendments in agriculture, ranging from their physical to their biological properties, have been described. Vermicompost constitutes a slow release source of nutrients that provides the plants with the nutrients when they are needed (Chaoui et al., 2003); in addition, several studies have shown that vermicompost performed better than the equivalent mineral fertilization when it constituted a relatively low proportion (10-20%) of the growing media of various plant species either in greenhouse or field trials (Atiyeh et al., 2000; Arancon et al., 2005). Furthermore, biologically active metabolites such as plant growth regulators (El Harti et al., 2001) and humates (Canellas et al. 2002) have been discovered in vermicomposted materials. Nevertheless, the effects of vermicompost have been described mainly on horticultural and ornamental plants and to a lower extent in forestry species. In addition, contradictory results are found in the literature concerning vermicompost effects on plant growth which might depend to a great extent on the plant species assayed. Besides, vermicompost effects might vary between genotypes of the same species. In this study, small proportions of vermicompost -either solid or liquid- were added to the potting media of different progenies of pine seedlings and without nutrient limitations, in order to investigate the existence of possible biological growth promotion effects, and the influence of plant genotype.

Materials and methods

Seeds with different genotypes belonging to five open-pollinated progenies of *P. pinaster* selected for superior growth stem form and branch characteristics were collected from an experimental orchard in Sergude (Galicia, NW Spain). Additionally a commercial mixture of seeds from different progenies was included for comparison. Five seeds belonging to the same progeny were sown in 4 L plastic pots. The basic potting mixture consisted on peat and perlite (1:1 v:v) where the following treatments were applied: (i) 0% substitution of peat by vermicompost (ii) 2.5 % substitution of peat by vermicompost; (iii) 5% substitution of peat by vermicompost; (iv) 10% substitution of peat by vermicompost; (v) 25% substitution of peat by vermicompost; (vi) vermicompost tea, in a dose equivalent to 2.5% of peat substitution by vermicompost; (vii) vermicompost tea in a dose equivalent to 25% of peat substitution by vermicompost. A slow-release mineral fertilizer was added to all the treatments and controls to avoid nutrient limitations. Pots were located in a greenhouse with controlled temperature and moisture following a randomized block design. After 20 weeks, the pine seedlings were harvested and their growth was assessed by measuring shoot height and diameter and biomass of shoots, leaves, and roots. The early ontogenic development of the plants was evaluated through the number of lateral branches and the amount of mature needles formed. Data were analyzed using GLM, with genotype and treatment as main factors. Seed weight and date of germination were introduced as covariables. Significant differences were further analysed with Tukey HSD test.

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Results

Most of the parameters measured were under a strong genetic control. Nevertheless the effect of the treatments was observed in most of the parameters measured. Both aerial and root biomass of the pine seedlings were significantly influenced by the treatments applied in the potting medium (aerial biomass: $F_{6, 751} = 2.9962$, $P < 0.05$; root biomass: $F_{6, 103} = 2.87081$, $P < 0.05$) (Figure 1). Whilst the lowest doses resulted in similar yields than the control (0% substitution), substitutions of 25% of the peat by solid vermicompost produced significant reductions of shoot and root biomass. Decreases in aerial biomass were due to significant reductions in needle biomass ($F_{6, 746} = 3.2216$, $P < 0.05$), diameter $F_{6, 751} = 5.8835$, $P < 0.01$) and height $F_{6, 744} = 4.392$, $P < 0.01$) of the shoot in seedlings with 25% of peat substitution. These reductions were similar for all the genotypes, significant interactions between treatment and genotype were only observed in shoot height ($F_{30, 744} = 1.882$, $P < 0.01$). Similarly, reductions in root biomass were attributable to the decrease in the abundance of fine roots ($F_{6, 103} = 3.20522$, $P < 0.05$) while thick roots were unaffected. The substitution of peat by vermicompost influenced as well the early ontogenic development of the seedlings as showed by the number of mature needles ($F_{6, 746} = 2.5900$, $P < 0.05$). This effect was also independent of plant genotype.

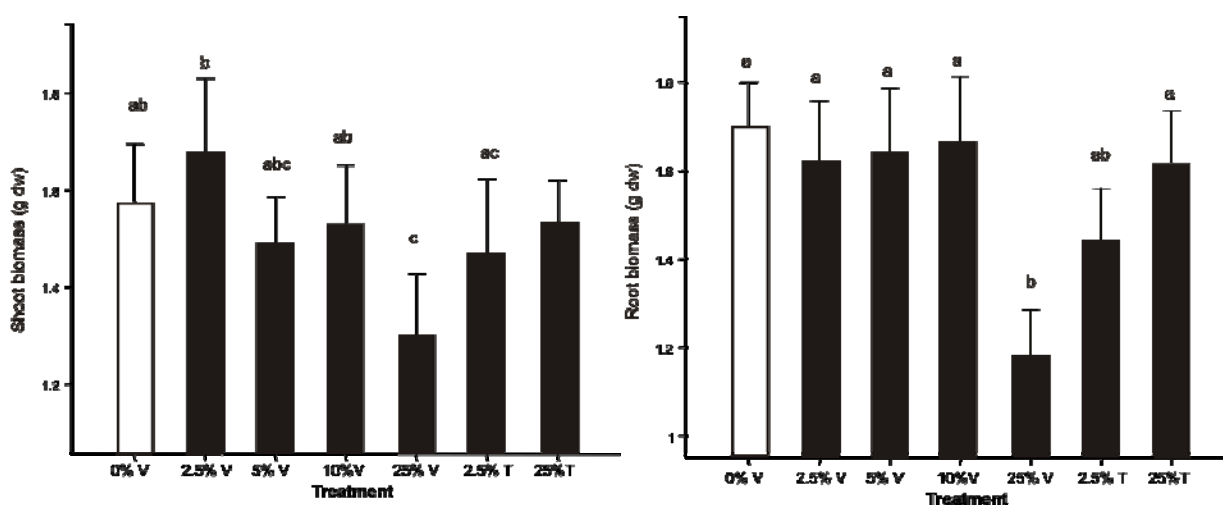


Figure 1: Effects of the treatments (0, 2.5, 5, 10 and 25% of peat substitution by vermicompost (V); and addition of vermicompost tea in doses equivalent to 2.5 and 25% of peat substitution (T)) on shoot and root biomass of the different progenies of pine seedlings.

Discussion

Although genetics have a strong influence on seedling growth during the first growing season of pine trees, nursery management practices are critical for an optimal post-transplant adaptation and field yield. Incorporation of vermicompost into the potting media could report beneficial effects derived from its biological properties. However, in contrast to previous studies, where vermicompost addition produced substantial increases in plant growth when enough fertilizers were provided as compared to mineral fertilization alone, in our study, even though the pine seedlings were grown under optimal nursery conditions, the substitution of peat by vermicompost did not produce any further beneficial effects in seedling growth and maturing as compared to peat with mineral fertilizer alone. Moreover, the highest dose of solid vermicompost produced significant decreases in seedling biomass. Generally all the progenies responded similarly to the treatments showing the strength of the effect.

Conclusions

In order to incorporate environmentally-friendly practices into pine seedling nursery, vermicompost can be introduced successfully in pine seedling growing media at low doses without detrimentally affecting plant growth. Higher doses could affect seedling growth influencing future field performance.

The results of this experiment provide one of the first approaches to the use of vermicompost as pot amendment in forest nursery as well as a clue for a better management of this kind of organic amendments by studying their interaction with the genotype of the plants.

Acknowledgments

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Effect of organic fertilizers on germination and seedling growth of tomato and suppression of soil borne diseases

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Key words: chemical fertilizer, organic fertilizer, germination, tomato

Abstract

Pot experiment was conducted to evaluate effects of organic and inorganic fertilizers on germination and early growth of tomato. Fertilizer treatments were Vermicompost (VC) from municipal solid waste, municipal solid waste Compost(MC), Cow manure(CM), poultry manure(PM), potting soil amended with chemical fertilizer (CF) and control treatment(C) (clay loam soil). Organic amendments significantly influenced emergence and elongation of seedlings and root to shoot ratio in seedling stage but did not have significant effect on seed germination in comparison with control treatment. Vermicompost, municipal solid waste compost and potting soil amended with chemical fertilizer stimulated emergence and elongation of seedling but cow manure similar to control and poultry manure treatments inhibited seedling emergence. Number of damping off plants affected by treatments. Using cow and poultry manure and CF treatments resulted deformities in tomato seedlings. Application of cow and poultry manure to agricultural soil without composting may lead to deleterious effects on vegetable crops. Overall, VC and MC could be an environmentally friendly in potting media with beneficial effects on seedling performance, but Application of cow and poultry manure to agricultural soil without composting may lead to deleterious effects on vegetable crops.

Introduction

Due to rising costs and uncertain future availability of peat moss, there is a need in the floriculture industry for alternative components in commercial potting substrates. In addition, because peat-based commercial potting substrates have low ion exchange capacities there is concern about the environmental impact of leachates containing high concentrations of chemical fertilizers (Bachman and Metzger, 2007). Despite the potential of organic wastes as fertilizer, their use in agriculture still required a lot of scientific research (Akanbi & Togun, 2002; Togun & et al, 2003). Germination and growth trials are a suitable method for measuring the potential of plant response, and information derived from such a trial could aid the potential marketability of the compost and manure. Germination trials alone might not indicate the availability of nutrients in the compost for plant use; only subsequent seedling growth can provide this information (Shana and Dewhirts, 2001). Growth media provides both physical support for the germinating seed and suitable environmental conditions in the surrounding media. The performance during the early growth stage will indicate if there are any phytotoxins within the media, which could adversely affect the growth. Poor performance during later growth stages might reflect a lack of available plant nutrients for sustained growth (Bowman and Durham, 2000).

Materials and methods

Pot experiment was conducted in 2007 in the research farm of the University of Shahid Beheshti, Zirab, Iran. Experimental design was randomized complete block in 3 replication and ten treatments. We used four kinds of organic amendment in these Experiments (Vermicompost (VC) from municipal solid waste, municipal solid waste Compost (MC), Cow manure (CM), poultry manure (PM)). Ten different potting mix treatments were prepared with addition each organic amendment at a rate of 50:50 and 100:0 with research farm soil (clay loam) and research farm soil amended with chemical fertilizer (CF) and free chemical fertilizer as a control (C) treatment. We tested the efficacy of ten treatments to enhance germination and growth of tomato seedlings. Tomatoes were grown in square plastic pots, 9cm in top width by 10 cm high. Fifteen pots used for each of treatment and general 150 per replication. Five tomato (*Lycopersicon esculentum L.*) seeds (cultivar: varamin) were planted in each pot. Pots were maintained under open area at natural condition in field. The number of seedlings successfully germinated in each pot was recorded for each treatment after one week and again after one week plants were thinned to one per pot by cutting off the smaller individuals with a razor blade at soil level. The end of experiment about fifth week, the height of the stem from soil to the base of the top leaves, numbers of leaves on each plant, shoot and root biomass, number of leaf, number of normal seedling was measured. Data were analyzed by MSTAT-C software.

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Results

Effects of organic amendments on seed germination of tomato were not significant ($p < 0.05$). Effect of organic amendments on Percentage of seedling emergence and damping off seedlings was significant ($p < 0.05$). In treatment, VC/100 had the highest seedling emergence (88 %). Lowest of seedling emergence (48.75 %) was obtained in PM/100 treatment, too. Effect of organic amendments on damping off seedlings was also significant ($p < 0.05$) and the highest damping off seedlings (51.25 %) was obtained in PM/100 treatment (Table 1). The greatest Shoot dry weight was recorded in VC/100 (1.97, $p < 0.05$). Effect of organic amendment on root dry weight was significant and CF, MC/50, MC/100, VC/50 and VC/100 produced the greatest root dry weight ($p < 0.01$). The highest Shoot and root dry weight were obtained in C treatment (0.45 and 0.1 %). Leaf number and stem height were affected significantly, too ($p < 0.05$). Results of mean comparison of these parameters were showed that VC/100 had the highest leaf number and stem height. The lowest leaf number and stem height (10.98 cm) were obtained in C treatment (Table 1).

Table1: Effects of organic amendments on early growth parameters of tomato

Treatment	Seed germination (%)	Seedling emergence (%)	damping off seedling (%)	Height (cm)	Shoot dry wt (gr)	Root dry wt (gr)	No. of leaf per plant
C	94 *	77.75 bc	22.25 de	10.98 d	0.45 g	0.1 c	4.6 f
CF	94.5	75.25 c	24.75 d	15.9 a	1.64 c	0.35 a	6 bcd
CM/50	93	68.5 d	31.5 c	13.3 bc	0.79 ef	0.2 b	5.5 cde
CM/100	94	61 e	39 b	11.88 cd	0.74 f	0.18 b	5.6 cde
PM/50	96	60 e	40 b	13.88 b	0.96 d	0.22 b	5.4 de
PM/100	95.3	48.75 f	51.25 a	12.38 bcd	0.91 de	0.19 b	5.1 ef
MC/50	97.3	83.5 ab	16.5 ef	15.88 a	1.81 b	0.38 a	6.2 abc
MC/100	96.5	72.25 cd	27.75 cd	16.25 a	1.78 bc	0.38 a	5.9 bcd
VC/50	94.3	86 a	14 f	16.5 a	2.07 a	0.35 a	6.5 ab
VC/100	93.8	88 a	12 f	17 a	1.97 a	0.39 a	6.7 a
Lsd 0.05	3.53	6.18	6.18	1.61	0.15	0.05	0.62

* Not-significant

Discussion

In between organic amendments, VC and MC produced the highest growth parameters. Percentage of seedling emergence and damping off seedlings in between treatments were difference significantly although their seed germination were not significant. It seems that pollution manure to pathogens is the main factor preventing manure treatments to produce optimum growth parameters.

Conclusions

Results of present study indicate that soil fertility seems to be most important limiting factor for tomato seedling production in C treatment. Therefore, improving seedling production of tomato through applying compost, enhance soil health and fertility, will result in better early growth and quantitative and qualitative yield of tomato, in general.

Acknowledgments

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Potentials of Cellulolytic Fungal Inoculants in Enhancing Vermicomposting Efficiency

Mahesh Chandra¹, Alok Kalra¹, Ashok Kumar¹

Key words: Vermicompost, Cellulase, *Trichoderma sp.*, and distillation wastes

Abstract

A large number of fungal and bacterial isolates were screened for their cellulase producing abilities. Six fungal strains were selected on the basis of their cellulase(s) producing potential on pure cellulose and agro-wastes/distillation wastes of aromatic plants. Among six strains, *Trichoderma citrinoviride*, *T. harzianum* and *T. reesei* proved themselves as potential cellulase(s) (FPase, endoglucanase and β -glucosidase) producing fungi and were able to grow on wide range of agrowastes including distillation wastes of aromatic plants. These fungi were further tested for their usefulness in the process of vermicomposting of distillation waste of the aromatic plant, geranium (*Pelargonium graveolens*) for determining their potential in reducing the time to compost and improving the quality. Significant reduction in C:N ratio was noticed in vermicompost obtained after inoculation of these fungi in vermicomposting process. Apart from it, *T. harzianum* improved level of available phosphorus. Increase in worm's population was also noticed where *T. reesei* and *T. citrinoviride* were inoculated.

Introduction

Scientifically, decomposition of organic matter especially in case of composting or vermicomposting is the result of enzymatic reactions of hydrolytic enzymes which are mainly produced by microorganisms present in the natural microbial flora. Although constituents of organic matter such as starch, pectin, different sugars and proteins are easily degradable but decomposition of recalcitrant polymer such as cellulose is tough (Dixon and Langer, 2006) and therefore indirectly affects the period of vermicomposting and quality of vermicompost. Cellulase(s) have been reported to be degraders of cellulosic materials. In the present investigation three efficient cellulolytic fungi were incorporated in the process of composting (without worms) and vermicomposting (with worms i.e., *Eisenia foetida*) of distillation waste of an aromatic plant, geranium for determining their potential in reducing time to compost and improving the quality.

Materials and methods

Bacteria and fungi were isolated and screened on carboxymethyl cellulose containing modified nutrient agar/broth and Mandels minerals salt agar/broth respectively. The selected isolates were grown with different agrowastes and evaluated for FPase, endoglucanase and β -glucosidase activities. The experiments on vermicomposting were conducted in 12 inches pots diameter with 1 kg twenty days old distillation waste of geranium. Pure cultures of *T. harzianum*, *T. citrinoviride* and *T. reesei* were inoculated to obtain a final concentration of 1.2×10^6 - 8.0×10^6 spores g^{-1} substrate. In case of vermicomposting, 50 earthworms were introduced in each pot. Moisture was maintained approximately 30-40%. Compost/vermicompost samples were chemically analyzed for total Kjeldahl nitrogen (TKN), total organic carbon (TOC), available phosphorus and potassium.

Results

Total organic carbon was reduced by 16.9 %, 10.0 % and 14.8 % when composted with *T. citrinoviride*, *T. harzianum* and *T. reesei* respectively. On the other hand TOC reduced upto 48.72 %, 42.57 % and 36.7 % in vermicompost where *T. citrinoviride*, *T. harzianum* and *T. reesei* were inoculated respectively. However, no significant increase in total Kjeldahl nitrogen was observed in compost inoculated with only fungi but significant increase in TKN was observed in vermicompost inoculated with *T. citrinoviride* and *T. reesei*; an increase of 19.2 % and 14.8 % respectively. On the other hand *T. harzianum* did not showed significant increase in TKN in vermicompost but surprisingly this fungus showed relatively higher (43.4 %) content of available phosphorus in compost and in vermicompost (58.9 %). A little increase in total potassium was also noticed in all treatments inoculated with fungi. In addition, substantial reduction in cellulose, hemicellulose and lignin was observed with *T. citrinoviride*. An increase in the number of worms was observed at the time of harvesting (90 days) vermicompost when inoculated fungal inoculants.

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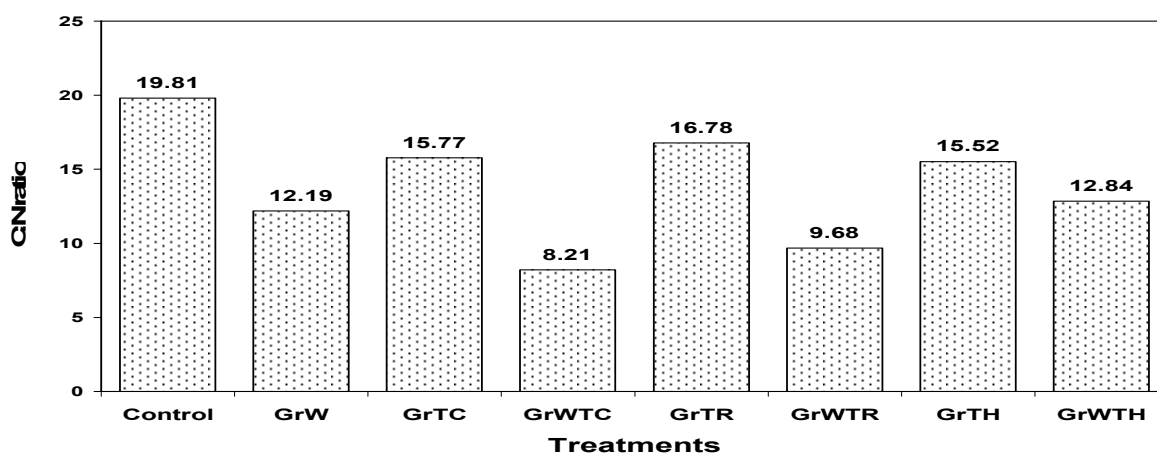


Figure 2: Effect of incorporation of cellulolytic fungi on the C: N ratio of obtained compost and vermicompost of distillation waste of geranium.

GrW- geranium waste+worms, GrTC- geranium waste + *T.citrinoveride*, GrWTC- geranium waste+worms *T.citrinoveride*, GrTR- geranium waste + *T.reesei*, GrWTR- geranium waste+worms *T.reesei*, GrTH- geranium waste + *T.harzianum*, GrWTH- geranium waste+worms *T.harzianum*, and Control- geranium waste composted without any inoculant

Discussion

TKN was found to be higher in vermicompost produced with fungi *T.citrinoveride* and *T. reesei* which may be due to enhanced decomposition of substrate by fungi also leading to decrease in organic carbon content. The decrease in C/N ratio (Fig.1) may also be due to increase in earth worm population (Nedgwa and Thompson 2000). It has been reported that a C/N ratio below 20 is indicative of an adequate maturity, a ratio of 15 or even less being preferable (Jimenez & Garcia 1989). An increase in phosphorus and potassium may be due to the production of organic acids during decomposition of matter which helps in solubilization of phosphorus and potassium. Cellulose and hemicellulose decrease was also observed where *T. citrinoveride* was inoculated. Rasal et al (1988) reported rapid decompositions of sugarcane trash by cellulolytic fungi including *Trichoderma*. Significant increase in the number of worms was also observed in vermicompost inoculated with *T. citrinoveride*. The increase in earthworms may be attributed to low C:N ratio (Nedgwa and Thompson, 2000).

Conclusion

Thus it could be concluded that the efficiency of vermicomposting process and quality of vermicompost can be significantly enhanced by application of efficient cellulase producing fungi like *T. citrinoveride*, *T. citrinoveride* and *T. reesei*.

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Poster presentations session 4.2

Plant available heavy metal concentrations in soil with compost versus mineral fertilization

Eva Erhart¹

Key words: biowaste compost, heavy metals, lithium chloride extract, soil saturation extract

Abstract

One concern about fertilizing agricultural soils with biowaste compost is the addition of heavy metals to the soil. As the ecological effects of metals, however, depend on the bioavailable fraction of heavy metals rather than on total concentrations in the soil, the objective of this study was to determine the water soluble, the potentially bioavailable and the total heavy metal concentrations in a field experiment after ten years with total applications of 95, 175 and 255 t ha⁻¹ biowaste compost (fresh matter). In the mobile heavy metal fractions as measured in soil saturation extract and LiCl extract no significant increases were detected except for Cu in the LiCl extract. Plant uptake data also showed increased Zn concentrations in compost fertilized oat grains. Cd concentrations in several crops were lower with compost fertilization than with no fertilization, while Cd concentrations in minerally fertilized potatoes were significantly higher. The total soil heavy metals contents showed no changes with compost fertilization, except for a slight increase of Zn with the highest application rate. In summary, the use of high quality biowaste compost at comparable rates gives no cause for concern with regard to bioavailable as well as to total heavy metal concentrations.

Introduction

The ecological effects of metals in the soil are related to mobile fractions rather than to their total concentrations. The water soluble fraction is commonly considered to represent the part which is directly available to plants and soil biota and which is susceptible to leaching. Neutral salt extractable fractions are thought to be readily bioavailable in the short term. This paper presents water soluble, readily bioavailable and total soil heavy metal concentrations measured in soil saturation extract, LiCl extract and aqua regia extract, respectively, after 10 years of different fertilization.

Materials and methods

The 'STIKO' field experiment was set up in the Obere Lobau near Vienna, Austria, in 1992. It includes three treatments with biowaste compost fertilization (9.5, 17.5 and 25.5 t ha⁻¹ yr⁻¹ (fresh matter) on average of 10 years), three treatments with mineral nitrogen fertilization (28, 45, and 62 kg N ha⁻¹ yr⁻¹, respectively, plus 42 kg ha⁻¹ P₂O₅ and 72 kg ha⁻¹ K₂O), five treatments with combined fertilization and an untreated control in six replications in a latin rectangle design. The biowaste compost used was produced at the composting plant of the City of Vienna in an open windrow process from source separated organic household waste and yard trimmings. Average heavy metal contents were 0.4 mg kg⁻¹ Cd, 24 mg kg⁻¹ Cr, 52 mg kg⁻¹ Cu, 19 mg kg⁻¹ Ni, 50 mg kg⁻¹ Pb, and 183 mg kg⁻¹ Zn (Erhart et al., 2008). The soil saturation extract was produced according to OENORM L1092 (1993), the LiCl extract following Husz (2001) and the aqua regia extract according to OENORM EN 13650 (2002). Plant heavy metal uptake data were measured by Bartl et al. (2002) between 1996 and 1998.

Results and Discussion

Cr and Ni concentrations in the soil saturation extract were between 1.1 and 2.0 µg kg⁻¹ and 3.2 and 5.9 µg kg⁻¹, respectively, both in the normal range for unpolluted soils. In LiCl extract, Cr was not detectable. The availability of Ni was not significantly increased by any of the fertilization treatments, which is also in agreement with plant uptake data for Ni (Cr was not measured in plants). Total soil concentrations of Cr and Ni, as well as those of Cu, Cd and Pb in the compost treatments were not significantly higher than in the unfertilized control and in the mineral fertilizer treatments. Soil pH (KCl) was around 7.2 irrespective of treatment. Soil C_{org} concentrations amounted to 1.83 % in the untreated control and were significantly higher in the compost treatments.

Cu concentrations in soil saturation extract were between 15.0 and 18.4 µg kg⁻¹ and showed no significant differences between the treatments. Easily available Cu (in LiCl extract) was increased with compost fertilization from 0.19 µg kg⁻¹ in the control to 0.23 and 0.25 µg kg⁻¹ in the medium and high

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compost treatments, probably due to complexation with low-molecular complexants. At pH values above 7, Cu is increasingly mobilized by soluble organic complexing agents which are produced by microbial degradation or by living roots. Plant Cu uptake was higher with compost fertilization than with no fertilization, even though not in all crops.

Cd was not detectable in the saturation and the LiCl extract. Plant heavy metal uptake data show a somewhat differentiated picture: Grains of oat and spelt and potato tubers had significantly lower Cd concentrations with compost fertilization than with no fertilization. In the potatoes which had received mineral fertilizer, significantly higher Cd concentrations were found, most probably due to the Cd input via superphosphate and triple superphosphate fertilizer. The total Cd loads imported via phosphorus fertilization appear small, but they are much more likely available to biota than the Cd bound in the soil (Sager, 1997).

Pb was not detectable in nearly all treatments both in the soil saturation extract and in the LiCl extract due to its very low solubility and availability at pH-values above 4. Also in the crops, Pb had not been detected.

Although total Zn concentrations were increased slightly, but not significantly from 67 mg kg⁻¹ in the control to 71 and 72 mg kg⁻¹ in the treatments with the highest application rates of compost, available Zn concentrations were not affected. The Zn concentrations in the soil saturation extract ranged from 6.5 to 10.8 µg kg⁻¹ and were in accordance with values measured in other agricultural soils. In the LiCl extract, Zn was not detectable. Plant uptake data showed increased Zn concentrations in compost-fertilized oat grains, while spelt and potatoes were not affected.

Conclusions

After 10 years with total applications of 95, 175, and 255 t biowaste compost (fresh matter) ha⁻¹, respectively, no significant increases were detected in the mobile heavy metal fractions as measured in soil saturation extract and LiCl extract except for Cu in the LiCl extract. Cu is, however, an essential micronutrient and Cu concentrations in the crops were in the normal range reported in the literature or below that. Plant uptake data, in addition, showed increased Zn concentrations in compost fertilized oat grains. Several crops had lower Cd concentrations with compost fertilization than with no fertilization, while Cd concentrations in minerally fertilized potatoes were significantly higher.

The total soil heavy metal contents showed no changes with compost fertilization, except for a slight increase of Zn in the treatments with the highest application rate. In summary, the use of high quality biowaste compost at comparable rates gives no cause for concern with regard to available as well as to total heavy metal concentrations.

Acknowledgments

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Fate of Organic Pollutants during Composting: a Review

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Key words: Organic pollutants, composting process, degradation, dissipation

Abstract

Available literature on the fate of organic pollutants (OPs) during composting has been reviewed. Most OPs are partly dissipated during composting which gives a good outline of potential improvement of organic amendment quality during the composting process. More research is necessary to characterize the proportion of non-extractable residues formed during composting.

Introduction

Compost application on cultivated soils contributes to the restoration of soil organic matter (OM) content. Organic pollutants (OPs) are potentially present in these composts and maximum legal concentrations have been defined in various countries. During the composting process, OPs are susceptible to be transformed, mineralized, volatilized, sorbed on OMs, in relation with OM degradation and humification, with the intense microbial activity and with specific properties of the compounds. The composting process includes 3 major phases (thermophilic, cooling and maturation) which involve specific microbial populations and temperature conditions influencing OPs behaviour.

Materials and methods

This study reviews the available literature focusing on the behaviour of OPs such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins and -furans (PCDD/Fs), polychlorinated biphenyls (PCBs), phthalates, linear alkylbenzene sulfonates (LAS) and nonylphenols (NP) during the composting process of organic materials only (no soil). These data were collected in a database and statistically analyzed. The data included came from studies dealing with all kinds of composts, laboratory or field composting experiments, real OP concentrations or spiked OP evolutions. The criteria for excluding data were an unclear description of the composting conditions, an unsuccessful composting process (thermophilic temperature lower than 45°C, anaerobic conditions) and data reporting in graphs without detailed comments in the text. This selection reduced the 26 studies originally reviewed to 16. Quantification of OP mineralization, volatilization, and bounding to OM can only be assessed by using ¹⁴C labelled OP, which was done in only two studies. Otherwise, the decrease of extractable OP is the result of the 3 mentioned processes that cannot be distinguished. In many cases, what is called "degradation" should be called "dissipation" referring globally to degradation, volatilization and potential formation of bound residues. Percentages of OP disappearance during the composting process were usually expressed on OP concentration basis, referring to the difference between initial and final OP concentration (when mass depletion goes faster than OP dissipation, the OP concentration increases during composting leading to negative percentages of dissipation). In few cases the percentages of OP disappearance referred to the difference between initial and final OP quantity (thus taking into account the mass depletion). Considering the temperature evolution reported in each study, the percentages of OPs disappearance were attributed to the thermophilic phase or to the full composting process.

Results and discussion

In most cases, PAHs dissipation was observed (Fig. 1, A and B). The median dissipation was only negative for the benzo[k]fluoranthene at the end of the composting (-2%) and varied from 10% for chrysene to 100% for acenaphthene and dibenzo[a,h]anthracene. The percentages of dissipation were usually greater considering the full composting process than the thermophilic phase only. Information on formation of non-extractable bound residues were available only for ¹⁴C-pyrene and ¹⁴C-phenanthrene and reached 12% (thermophilic phase only) to 22% during the composting process. Fewer references concern PCDD/F and PCBs behaviour during composting. Concentrations usually increased because of the faster degradation of OM (Fig. 1, C and Tab. 1). However, the concentrations usually remained lower than quality standards. Finally, median values of decrease in

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OP concentration during composting was 85% for LAS at the end of thermophilic phase, 87% for nonylphenols, 62% for di(2-ethylhexyl)phthalate (DEHP) and 46% on OP quantity basis for DEHP at the end of the composting process (Tab.1).

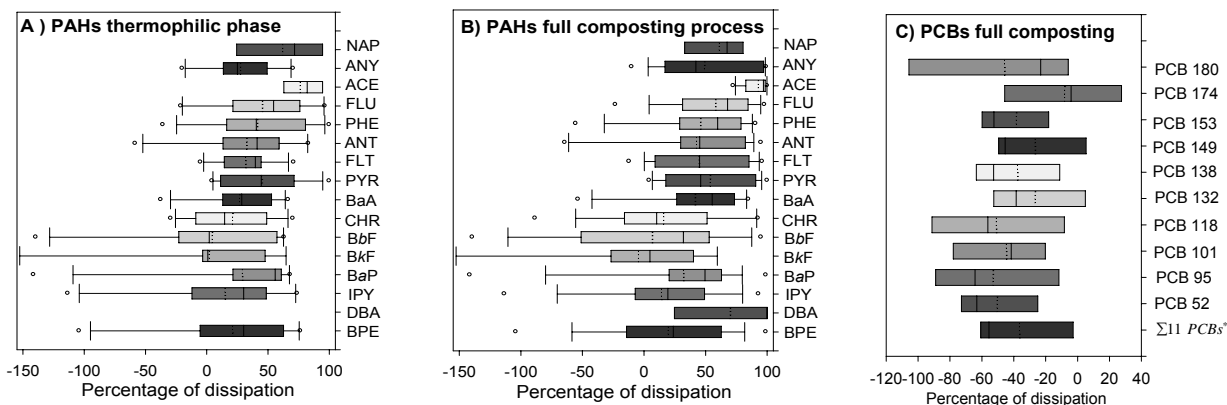


Figure 1: Distribution of the percentages of PAH dissipation (calculated on concentration basis) at the end of the thermophilic phase (A) at the end of composting (B) and of PCBs at the end of composting (C). Line: median; dotted line: mean; box: 25th and 75th percentile; lines with whiskers: 10th and 90th percentiles; dots: outside values. NAP: Naphthalene, ANY: acenaphthylene, ACE: acenaphthene, FLUO: fluorene, PHE: phenanthrene, ANT: anthracene, FLT: fluoranthene, PYR: pyrene, BaA: benzo[a]anthracene, CHR; chrysene, BbF: benzo[b]fluoranthene, BkF: benzo[k]fluoranthene, BaP: BaPbenzo[a]pyrene, IPY: indeno[1,2,3-cd]pyrene, BDA: dibenzo[a,h]anthracene, BPE: benzo[ghi]perylene. Source: 6 reports

Tab. 1: Distribution of the percentages of dissipation of other organic compounds during composting (calculated on concentration basis except for 2 studies).

OP	Thermophilic phase			Full composting process			Number of reports
	Number of samples	Number of detections	Dissipation (%) median (mini, max) or single value (%)	Number of samples	Number of detections	Dissipation (%) median (mini, max) or single value (%)	
∑15 PAHs	5	5	39 (13; 63)	5	5	37 (-14; 79)	1
∑11 PCBs	5	5	-22 (-85; 38)	5	5	-56 (-66; 32)	1
TCDD	2	2	-40 (-125; 45)				2
TCDF	1	1	-71				
DEHP	1	1	31	5	5	62 (18; 94)	4
DEHP	7*	7*	96* (69*; 99*)	2*	2*	46* (34*; 58*)	
LAS	5	5	85 (77; 91)				1
NPE	1	1	96				2
NP	1	1	24	1	1	87	

* Dissipation of OP quantity during composting.

TCDD/F: tetrachloro dibenzo-p-dioxins and -furans, DEHP: di(2-ethylhexyl)phthalate, NP: nonylphenol; NPE: nonylphenol ethoxylates.

Conclusions

Most often, OP concentrations decreased during composting. The reported results highly varied with the composting process and the composted wastes. The dissipation intensity also varied with the chemical nature of the OPs. More research is necessary to characterize the proportion of non-extractable residues formed during composting: results of OP concentrations in compost correspond to extractable OPs using appropriate methods and they do not take into account the fraction of non extractable OPs bound to OMs. Moreover few authors studied the temperature influence of OP dissipation which could provide interesting information on how to conduct the composting process to optimize OP degradation.

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Poster presentations session P1

MBT for a Sustainable Development – Vision 2020

Reinhard Schu¹, Kirsten Schu²

Key words: Mechanical-Biological Treatment, NMT-Process, BioFluff, sustainable waste treatment, wet mechanical separation

Abstract

Mechanical-Biological Treatment today is not the ultimate answer to a modern waste management. The poster presents a new, modular Waste Treatment Technology meeting the standards for a sustainable development and already implemented on industrial scale. By using a stepwise wet separation process (NMT-Process) the waste is separated into unpolluted inert and organic fractions (BioFluff) while the process water contains the easily biodegradable matter as well as salts and heavy metals. Biogas is produced from AD of the process water and the remaining sludge serves as pollutant sink for the process.

Introduction

In waste management, the idea of sustainability is represented in the “Vision 2020” and most recently in the European Waste Framework Directive with its proposed five step waste hierarchy. Accordingly, in Germany the material cycle is to be closed completely in 2020 at the latest. This can only be achieved by high-grade utilisation of secondary products and by recycling, making landfills dispensable. However, discharge of pollutants will still be necessary; a 100 % recovery is not yet technically feasible.

We present a concept, suitable for household waste, bio waste and other mixed materials, that fulfils the high requirements for a sustainable waste management. Our concept represents the technical answer to a landfill-independent waste management.

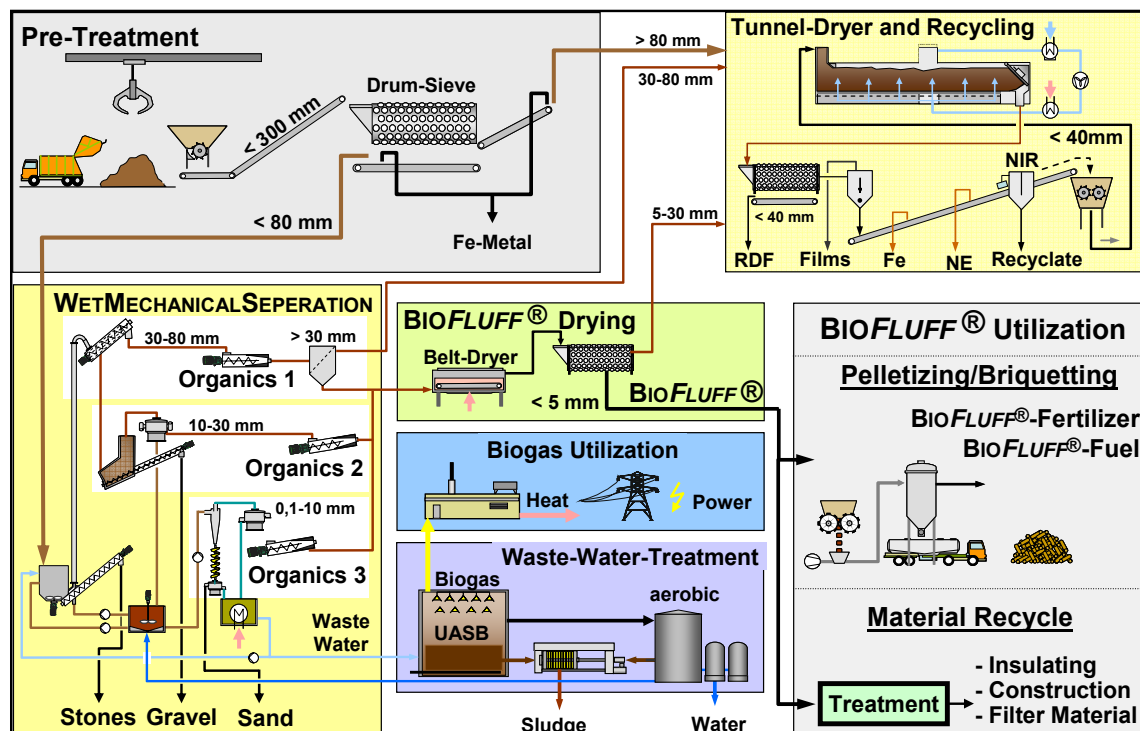


Figure 1: Sustainable MBT-concept – Process Flow Diagram Source: Schu, 2007

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The MBT-concept developed by EcoEnergy is based on modules and can easily be adapted to improve the performance of existing MBT- and composting plants. The modules are:

- Module 1: mechanical pre-treatment
- Module 2: Tunnel-Dryer and recycling
- Module 3: wet mechanical separation (Nass-Mechanische Trennung, NMT-Process)
- Module 4: waste water treatment and biogas utilization
- Module 5: BioFluff drying
- Module 6: BioFluff conditioning and utilization

The core component of the concept is Module 3, the wet mechanical separation of the fine fraction < 80 mm. This fraction is basically a mixture of water, inert matter (sand, stones and glass) and native and fossil organic matter. Main purpose of the treatment is the production of materially recyclable inert fractions and materially and/or energetically recyclable organic fractions.

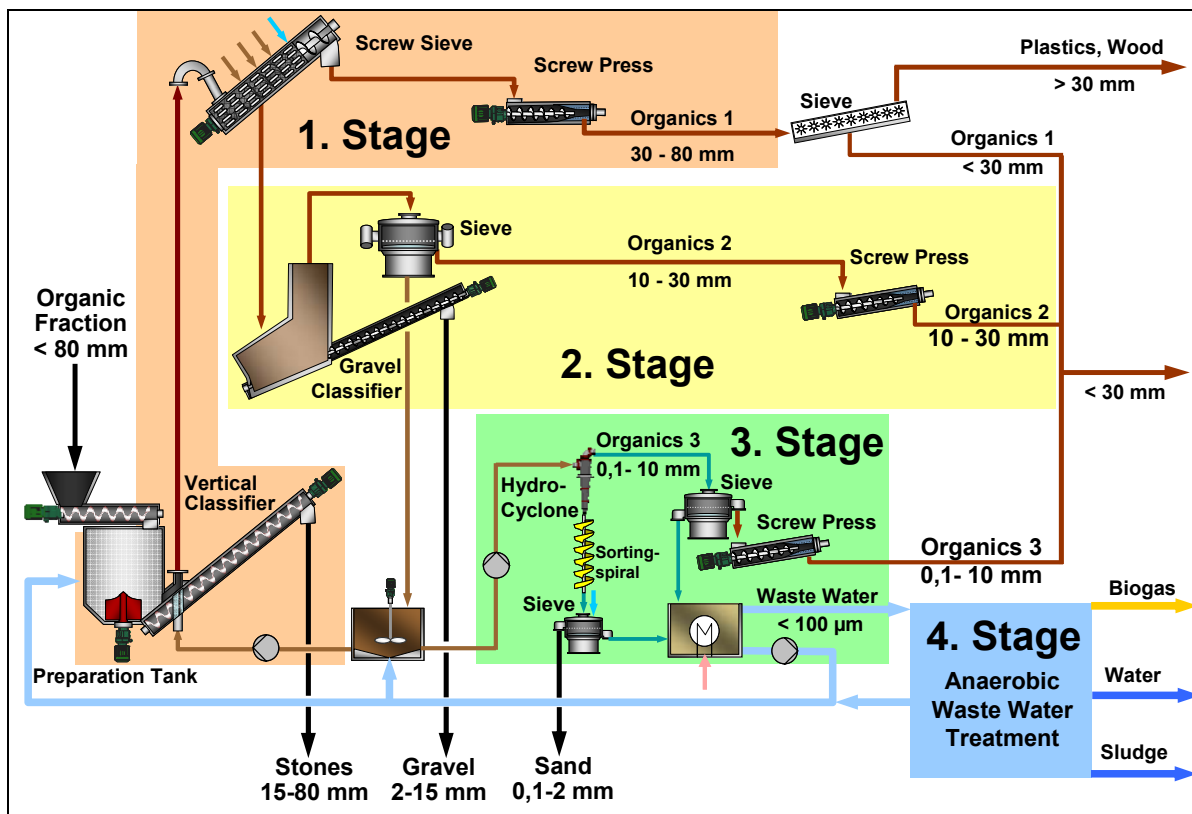


Figure 2: NMT-process – Process Flow Diagram Source: Schu, 2007

In 2006 and 2007 tests with a pilot plant proved the large-scale feasibility of NMT and the quality of the fractions produced from MSW as well as from separately collected biowaste.

We could further verify by experiment, that 65 % to 80 % of the biogas production, generated with AD from the total material, is also yielded from AD of the process water. The process yields low polluted inert fractions for construction purposes as well as sand-free organic fractions, containing only unpolluted organic matter, separated in fossil and native organic matter.

Due to the very low pollution, the native organic fractions (BioFluff), even from MSW without separate collection, fulfil the requirements for the German compost application as a high quality fertilizer. The process also reduces the salt content of the BioFluff so that BioFluff also meets the specifications for use in coal fired boilers for CO₂-free energy utilisation.

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Integrated Systems for Sustainable Management of Animal Manure in Alpine Regions

Silvia Silvestri¹, Luciano Sicher¹

Key words: animal manure, anaerobic digestion, co-digestion, renewable energy, alpine environment.

Abstract

The method of work adopted to define a new system for the management of animal manure is briefly exposed. The size and management of stables, the amounts of animal manure and its quality, the storage capacity and spreading modality, the nutrient balance of fields related to the crop production and the ecological situation of each considered reality are the main indicators used for the redaction of feasibility studies aimed at evaluating the sustainability of new solutions based on the anaerobic digestion in centralized plants. The energy balance and an estimate of the costs for the realization of the integrated systems complete the studies.

Introduction

In some areas of Trentino, as in many other alpine regions, a process of intensification and specialisation of animal husbandry has taken place in recent decades. A new reality has emerged that doesn't fit that earlier image: milking cows spend all their lifetime in the stable eating forage and concentrates mainly bought outside of the territory. Permanent meadows and pastures are often underutilized. At the same time, insufficient storage capacity, inadequate application of animal waste slurry using obsolete equipment, increased ammonia emission, and release of odours have a strong impact on alpine ecology. This puts pressure on the relationship between residents and tourists.

Agriculture and tourism have to coexist in the same areas, but with different needs in terms of landscape use and requirements. Thus, both farmers and local governments are urging new approaches in the treatment of animal manure based on the sustainability principles. New European policies and actions aimed at promoting and stimulating the use of biomass as renewable energy source are helping to identify the best available techniques for the livestock manure stabilization.

Materials and methods

Specific feasibility studies on manure as renewable energy source addressed four different areas. A deep cognitive survey was carried out on the livestock situation, crops production and nutrient balance (nitrogen and phosphorus) at both the farm and district level. The evaluation of potential risks of soil pollution and worsening of air and water quality completed the local survey.

The second step of the study analyzed the technological solutions which could be effective in reducing the environmental impact of the manure. Both composting and anaerobic digestion (AD) were considered, highlighting advantages and disadvantages of each one.

A third aspect considered the end-use of digested manure with a proposal of introducing innovative machinery and equipment to minimize odour release and to enlarge the application windows during the growing season. Finally, the energy balance of the proposed technical solutions was considered, i.e. the expected efficiency in terms of biogas production and the possible allocation of thermal and electrical energy.

Results

Results and possible solutions differed considerably from one area to the other with respect to the local starting situation. The amount per year and dry matter (DM) content of manure, i.e. solid manure (20% DM) or liquid manure (10% DM) suggests the following technology: composting in the first case, and AD in the second one. Tables 1 and 2 summarize the most significant data for one specific study area among the four investigated.

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Tab. 1: Results of the cognitive survey on one of the studied areas *Giudicarie Esteriori*

Item	September 2006	Note
Farms n°	68	Dairy/beef cattle, pigs, rabbits, broiler
Livestock Units (LU)	4.071	3.586, 142, 50, 69
Slurry + liquid manure (m ³ y ⁻¹)	70.000	
Solid manure (tons y ⁻¹)	12.000	
Maize silage 70 ha (tons y ⁻¹)	4.550	To improve energy production
Grass silage + apple + potatoes (tons y ⁻¹)	1.200	To improve energy production
Arable crops + permanent meadows (ha)	2.132	Usable agricultural area of the 4 municipalities excluded biotopes and the steepest permanent meadows (417 ha)
Animal density (LU ha ⁻¹)	1,91	Rural Development Plan 2000-06: Dairy cattle max 2,5 LU ha Beef cattle max 2,0 LU ha

Tab. 2: Expected outputs in the option of one centralized plant (with the technical support of specialized companies)

<i>Item</i>	<i>Yields</i>	<i>Input biomass</i>
Total input biomass (tons y⁻¹)	~ 87.750	First hypothesis
Biogas (m³ y⁻¹)	~ 3.222.000	Animal manure + maize silage + grass silage + apple + potato
Electric energy (kWh y⁻¹)	6.260.000	Excluded the self consumption (8%)
Thermal energy (kWh y⁻¹)	3.800.000	Excluded the self consumption (50%); available heat for the local cheese factory and other users
Installed electric power of engine (kW)	997	
<i>Item</i>	<i>Yields</i>	<i>Input biomass</i>

Discussion

The general proposal to realize one centralized AD plant seems to be the best hypothesis when considering the total number of local farms and the whole usable agricultural area. It also takes into account the necessity of preserving protected areas such as biotopes and the steepest permanent meadows. The co-digestion of manure and maize or grass silage is suggested because these are energy-crops which can considerably increase biogas yield. At the same time, the AD of organic residues from agriculture simplifies the authorization procedure for the digested slurry application in the field.

Concerning renewable energy production, two main streams have to get a proper use: the electric power obtained by cogeneration is put in the network; the heat (thermal energy), which is consistent in terms of quantities (Table 2) will be partly re-used within the plant, the rest is available for external users, here the local cheese factory.

Conclusions

Anaerobic treatment of manure makes it possible to convert the current problem into a resource by producing biogas and renewable energy, in alignment with European trends. Other advantages of AD are the abatement of bacteria and viruses, inactivation of plant seeds, reduction of odour impact, and greenhouse gas emission. The acceptance of the proposed solution (centralized plant) by the local population necessarily implies the involvement of deputies in the definition of each step of the project and a constant activity of information of the people on the main results.

Aknowledgements

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The voluntary certification processes about the compost and the compostable products in Italy

Massimo Centemero¹, Werner Zanardi¹

Key words: certification process, compost, compostability, biodegradability

Abstract

The Italian Composting Association (CIC) has introduced two certification programs in Italy. The first program is on the end product (compost) and the second on the compostability of products made with biodegradable polymers (bioplastics and cellulose fibre).

Topic

The Italian Composting Association (CIC) is a non profit organisation founded in 1992 and which associates entities, public and private corporations and other associations working in the composting field (producers of compost soil fertilizers, machinery and agricultural implements and research associations etc).

There are currently 110 associate members and those producing high quality compost represent more than 70% of the national production (more than 1.000.000 tons per year of compost).

Among CICs' missions are the development of source separated collection, recycling and the exploitation of organic waste, within a context of integrated waste management. As a final target CIC aims at obtaining high quality composts, which can be sold and utilised in such different fields as agriculture, landscaping and environmental recovery, etc. CIC works to coordinate and help its company members through legal and technical consulting functions and works on legislative lobby activities. CIC collaborates with the most important state offices for the elaboration of laws at a national level; recently CIC is a part of the "fertilizer commission" working in MIPAAF (agriculture Ministry) to represent this industrial sector. At a European level it works with the teams created by the UE on environmental topics, on waste and soil (risk of desertification and lack of organic matter).

Recently CIC has dedicated resources to the certification process. In 2003 it created an important initiative concerning compost quality certification for its members, thus starting a programme of voluntary certification which at present has certified 17 composting plants with 18 products with a CIC quality label whose name is "Composr Qualità CIC". The quality control has been created to make it easier for end users (farmers, soil producers, state administrations and citizens) to find information on the quality of the input materials (this piece of information regards guarantees about the origin) and on the end product. CIC, with its label, wants to guarantee the product and give added value to the compost produced, ensuring transparency, reliability and quality to its final users. Recently the revision of its rules has introduced some important elements:

- creation of a quality committee which oversees certification guidelines;
- introduction of the concept of organic waste origin and traceability;
- updating with the latest legal news.

The members selling compost with a CIC quality label represent about the 25 % of total national product.

Another certification programme which has recently been introduced deals with the compostability of products made with biodegradable polymers (bioplastics and cellulose fibre) whose name is "Composabile CIC".

The reason for which CIC has developed this programme is linked to the problem of the difficult degradability of plastics and to the fact that plastic ends in the end compost reducing its quality.

After a long experimental activity CIC has developed a method to establish the compostability/disintegrability of biodegradable products (bin liners for source separated collection, shoppers, objects for catering etc) using 13452 now 14955 UNI EN standard. Through testing the compostability with a real scale test, CIC aims at promoting the use of biodegradable products. The certification enables consumers to identify them (when they become waste), thus allowing a better recycling process and being classified like the other organic waste.

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The labels of these two certifications are the follow:



Figure 1: Label of “Compost Qualità CIC”



Figure 2: Label of “Compostabile CIC”

Poster presentations session P2

Improving vermicomposting of animal manures: effects of rate of manure application on carbon loss and microbial stabilization

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Key words: decomposition; pig slurry; microbial respiration; microbial populations

Abstract

Here we study how the rate of application of manure affects microbial biomass and activity and carbon losses during the vermicomposting of animal manures. We found that earthworms increased microbial biomass and were more active in reactors fed with high application rate of slurry, but C loss was not influenced by rate of pig slurry applied. We therefore recommend the use of low application rates of manure when the objective is the microbial stabilization of the residue.

Introduction

The decomposition systems depend on inputs of resources, that is, the components of the system do not have any control on their availability (regeneration). Vermicomposting is the process whereby organic residues are broken down by earthworms and microorganisms (Domínguez, 2004). Addition of manure has been shown to be of critical importance and determines most of the changes that take place during vermicomposting (Edwards, 2004).

Materials and methods

We designed continuous feeding reactors in which new layers of manure were added sequentially to form an age gradient inside the reactors. We compared two application rates of pig slurry (1.5 and 3 kg) and set up 6 reactors for each one; half of the 12 reactors initially contained a population of 500 earthworms (*Eisenia fetida*). At the end of the experiment (i.e. after 36 weeks), the vermireactors comprised 12 modules with an increasing gradient of age, resembling a soil profile, from upper to lower layers as follows: 2, 4, 7, 8, 11, 18, 21, 25, 27, 29, 33 and 36 weeks. At each sampling time the vermireactors were dismantled and the modules isolated to avoid earthworm escape. The earthworms were then manually removed from the substrate, weighed and counted; we found earthworms only in layers of 2, 4, 7, 8, 11 and 18 weeks of age. In order to better understand the effects of rate, earthworms and time on the decomposition of pig slurry, the figures represent the values of the initial or raw pig slurry, the mean of the values corresponding to 2-18 week-old layers (layers in which earthworms were present at sampling time) and the mean of values corresponding to 21-36 week-old layers (oldest layers without earthworms at sampling time). Five samples of substrate per module were taken at random and gently mixed for biochemical analyses, i.e. total C, microbial biomass-C (C_{mic}) and basal respiration (Alef and Nannipieri, 1998).

Results

The vermicomposting process was characterized by a continuous and significant loss of C over time (i.e., age of layers), and this loss did not depend on the rate of application of pig slurry but did it on earthworm presence (Fig. 1a). Earthworms enhanced the C_{mic} of the pig slurry during vermicomposting; thus, in layers with earthworms (2–18-week old layers) C_{mic} reached values close to or higher than in the fresh pig slurry (1.5 and 3 kg dose, respectively)(Fig. 1b). However, in the older layers (21–36-weeks old), earthworms produced a decrease in C_{mic} values. Microbial activity (basal respiration) was higher in the system to which the highest doses of pig slurry were added, but decreased significantly over time during the vermicomposting process (Fig. 1c). Values of basal respiration were higher in young layers (2–18-weeks old) than in old layers (21–36-weeks old) depending on earthworm presence.

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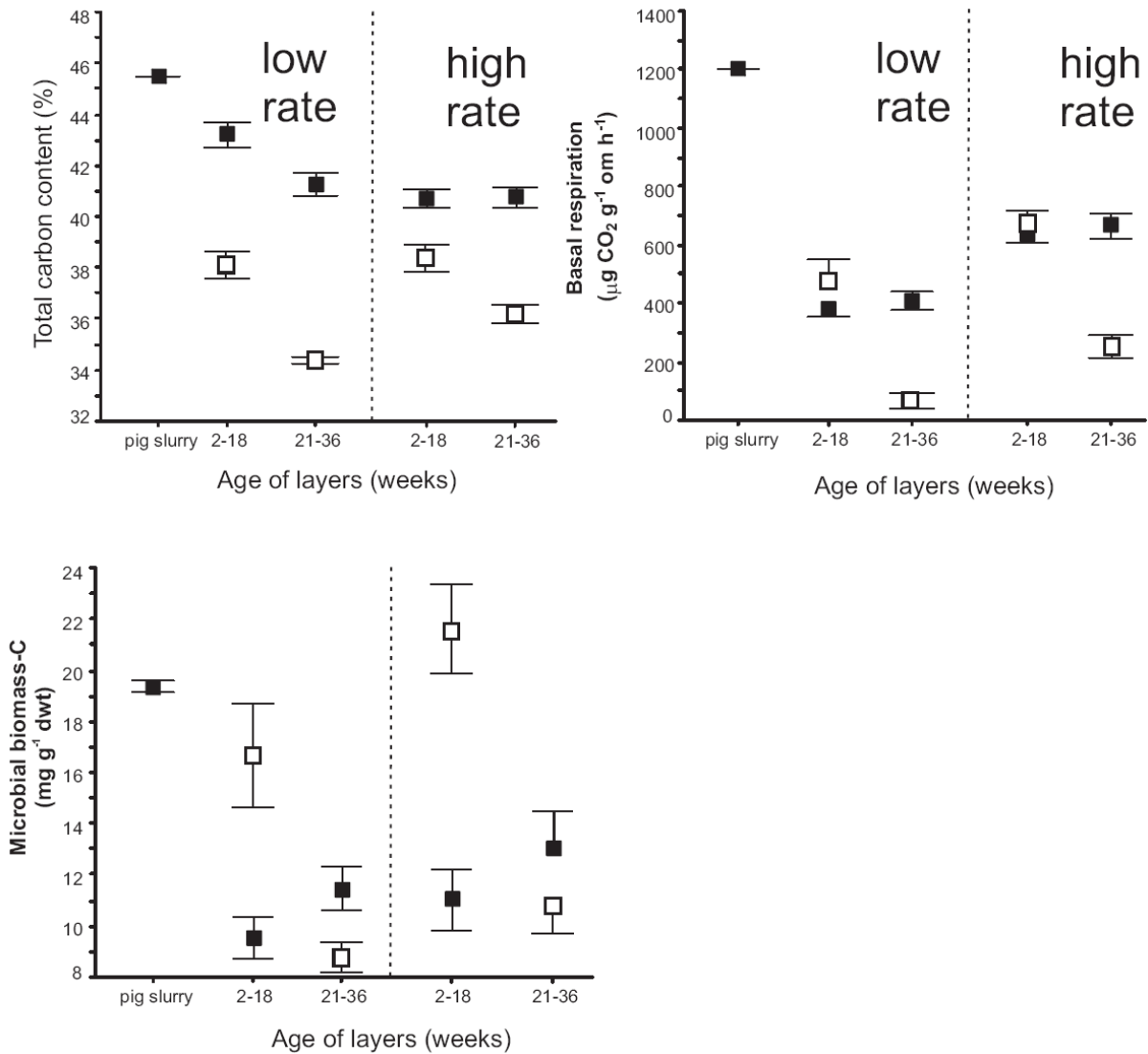


Figure 1 Changes in total C (a), microbial biomass-C (b) and basal respiration (c)(mean \pm S.E.) in layers of reactors fed with 1.5 kg (a) and 3 kg (b) of pig slurry with (white squares) and without earthworms (black squares). The vertical distributions of the variable values corresponding to the age of layers of pig slurry (from 2 to 36 weeks) are represented on the y-axis.

Discussion

We found that earthworms increased microbial biomass and were more active in reactors fed with 3 kg of slurry. However the differential rates of respiration were not reflected in C losses. The results thus showed that loss of C was not affected by the rate of pig slurry applied. We conclude that despite the strong effect that the rate of manure has on microbe-earthworm relationships, it did not affect carbon losses. We therefore recommend the use of low application rates of manure when the objective is the microbial stabilization of the residue.

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Earthworms accelerate decomposition modifying the structure and function of microbial communities during vermicomposting

Manuel Aira¹, Cristina Lazcano¹, Jorge Domínguez¹

Key words: fungal populations; functional diversity; microbial activity; carbon mineralization; metabolic quotient

Abstract

Here we show that the earthworm *Eisenia fetida* is able to promote a more efficient C loss during vermicomposting of pig slurry through the modification of structure and physiological capabilities of microbial communities. Thus, we found that earthworm presence was associated with increases in microbial biomass and activity, and also modified the physiological profile of microorganisms involved in decomposition. This led to an improved rate of C loss.

Introduction

Although microorganisms are largely responsible of organic matter decomposition during vermicomposting (Domínguez, 2004), earthworms may also affect to rates of decomposition directly by feeding on and digesting organic matter and microorganisms, or indirectly affect them through their interactions with the microorganisms, basically involving stimulation or depression of the microbial populations (Edwards, 2004). We tested the general hypothesis that microbial populations, and especially fungi, are enhanced by earthworm activity, and also whether earthworms are able to modify the biodiversity of microbial populations, and its relation with the function of the system. In addition we examined the metabolic quotient to assess the relationships between earthworm and microbes.

Materials and methods

To do this we designed experimental continuous feeding reactors. The reactors were comprised of modules that were added sequentially to the system. The modules, which resembled sieves, were made of PVC - the external diameter of each was 30 cm with a height of 2 cm giving a volume of 1413 cm³. The bottom of the modules was a mesh size 5 mm, which allowed earthworms to move between modules. Each reactor was initially composed of one module containing vermicompost, in which earthworms were placed, and another module containing a layer of 1.5 kg of fresh pig manure (300 g of dry mass, moisture content 80±10%). We set up a batch of six reactor, three without earthworms (control) and three containing 500 mature earthworms (ca. 90±10 g, fresh weight) (*Eisenia fetida*) each. At the end of the experiment (i.e. after 36 weeks), the reactors comprised 12 modules with an increasing gradient of age, resembling a soil profile, from upper to lower layers as follows: 2, 4, 7, 8, 11, 18, 21, 25, 27, 29, 33 and 36 weeks. For sampling, the reactors were dismantled and the modules isolated to avoid the earthworms escaping. Five samples of substrate per module were taken at random and gently mixed for biochemical analyses, i.e. microbial biomass-C, ergosterol content, basal respiration, Biolog® Ecoplate analysis and metabolic quotient (ratio basal vs microbial biomass-C) (Alef and Nannipieri, 1998).

Results

The process of vermicomposting was characterized by a continuous and significant loss of C through the increasing age of layers of reactors until 21 weeks (Fig. 1a). Ergosterol concentration increased in layers of reactors where earthworms were present, 2-, 4-, 7-, and 11-week-old layers, with a peak of 53±12 µg g⁻¹ dw in the 4-week-old layer, values higher than those found in the fresh pig slurry (Fig. 1b). The metabolic quotient revealed that respiration of microorganisms was significantly lower through the entire profile of vermireactors with earthworms (0.07±0.02 µg CO₂ µg⁻¹ C_{mic}) than in vermireactors without earthworms (0.18±0.02 µg CO₂ µg⁻¹ C_{mic}, Fig c).

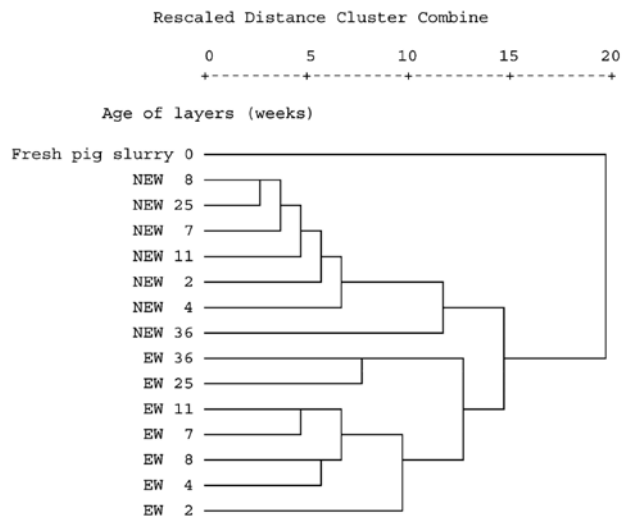
Discussion

We found that decomposition of pig manure has two stages characterized by the presence or absence of earthworms. Thus, the presence of earthworms was related with increases in overall microbial biomass and activity which decreased when earthworms left the substrate; the same pattern was observed for fungi. Furthermore, earthworms modified the physiological profiles of microbial

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communities of pig manure, increasing the diversity of substrates utilized (Fig. 2). In addition, earthworms promoted a more efficient use of energy of microbial communities as the metabolic quotient showed. The rate of carbon loss was almost twice in the presence of earthworms, revealing faster decomposition.

Figure 2: Cluster analysis of the Biolog Ecoplate physiological profiles from layers of 0, 2, 4, 7, 8, 11, 25, and 36 weeks of age in vermireactors without earthworms (NEW) and with earthworms (EW). Clusters were determined by the Ward method and by Euclidean distance.



Our data match with the recent findings that for maintaining essential processes the functional properties of present species are at least as important as the number of species per se. This is in accordance with the “insurance hypothesis” which states that a large number of species is probably essential for maintaining stable processes in changing environments (Loreau et al., 2001), as presence of earthworms would have promoted in pig manure. The homogenization of the substrate by earthworms could have led to a “community conditioning” (Griffiths et al., 2001) where microorganisms increase that are specialized in metabolizing compounds produced or released by earthworms, improving the rate of mineralization and decomposition of the substrate, as it was previously reported with cellulose decomposition (Aira et al., 2006).

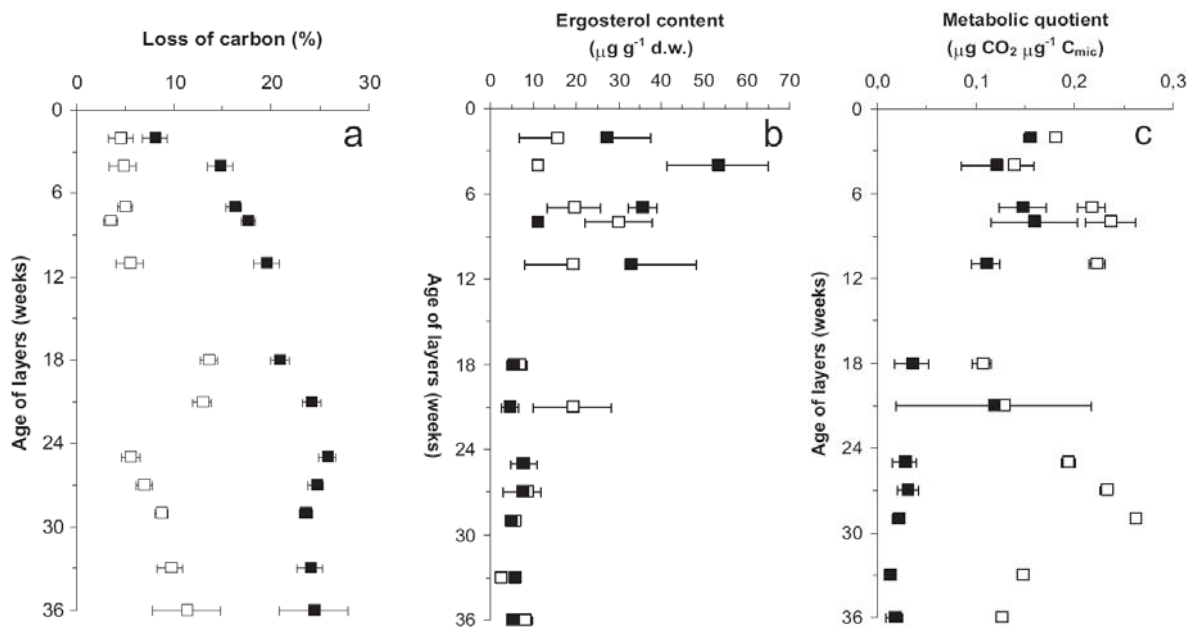


Figure 1: Loss of C (a) and changes in ergosterol content (b) and metabolic quotient (c) in layers of vermireactors with (closed squares, n = 3) and without (open squares, n = 3) the earthworm *E. fetida*. The vertical distributions of variable values (mean \pm SE) are shown on the y-axis, i.e., corresponding to age of pig slurry layers, between 2 and 18 weeks.

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Earthworms Trigger Enzymatic Activities through the Increase of Microbial Biomass and Activity during Vermicomposting of Pig Slurry

Manuel Aira¹, Cristina Lazcano¹, Jorge Domínguez¹

Key words: fungal populations; functional diversity; microbial activity; carbon mineralization; metabolic quotient

Abstract

We assessed whether there is a relationship between earthworm activity, microbial biomass and the activation and dynamics of several enzyme activities during vermicomposting. Since decomposition systems are donor controlled we also study the effect of different rates of application of manure. For this, we carried out an experiment in which low and high rates (1.5 and 3 kg respectively) of pig slurry were applied to small scale reactors with and without earthworms.

Introduction

Enzyme activities have been used widely as an index of soil fertility or ecosystem status because they are involved in the biological transformations of native and foreign compounds in soils (Tate, 2000). Several enzymatic activities have been measured to describe organic matter decomposition in two microbial-driven processes, composting and vermicomposting (Aira et al. 2007). Thus, it is necessary to determinate the relationships between microbial populations and enzymatic activity during organic matter decomposition; further, it is also important to quantify the amount of extracellular enzyme activity. Such knowledge would lead to better understanding of how earthworms and microorganisms interact during the decomposition of the organic matter.

Materials and methods

We designed continuous feeding vermireactors with separated layers to date them. We set up six reactors with earthworm (500 mature initial population, ca. 85 g) and six reactors without (control). New layers with fresh pig slurry (1.5 and 3 kg fresh weight, six reactors per rate of pig slurry application) were added when the last ones were eaten by the earthworms and the experiment ended after 36 weeks. At the end there were nine layers with an age gradient of 0, 4, 8, 13, 21, 25, 27, 33 and 36 weeks from upper to bottom layers. Five samples of substrate per module were taken at random and gently mixed for biochemical analyses, i.e. microbial biomass C (Cmic), β -glucosidase, cellulase, alkaline phosphatase and protease activities. Data were analyzed under a split plot repeated measures ANOVA design. (Alef and Nannipieri, 1998).

Results

Earthworms stimulated microbial growth which decreased once earthworms left the slurry. This increase was related to the initial activation of the microbial enzymes studied: β -glucosidase, cellulase, alkaline phosphatase and protease as correlations between microbial biomass and activity and enzymes showed (Figure 1). These strong relationships indicated an increase of intracellular enzyme activity (Table 1). In the aged slurry enzymatic activity through layers was to microbial biomass. Further, these differences in overall enzyme activity agree with the variation found in extracellular enzyme activity suggesting certain dependence on substrate availability. We found that extracellular enzyme activity increased with rate of pig slurry, indicating a baseline of enzyme activity through decomposition. Thus, rate of pig slurry should be chosen carefully if vermicompost is going to be used as organic amendment, since earthworm activity did not decreased it.

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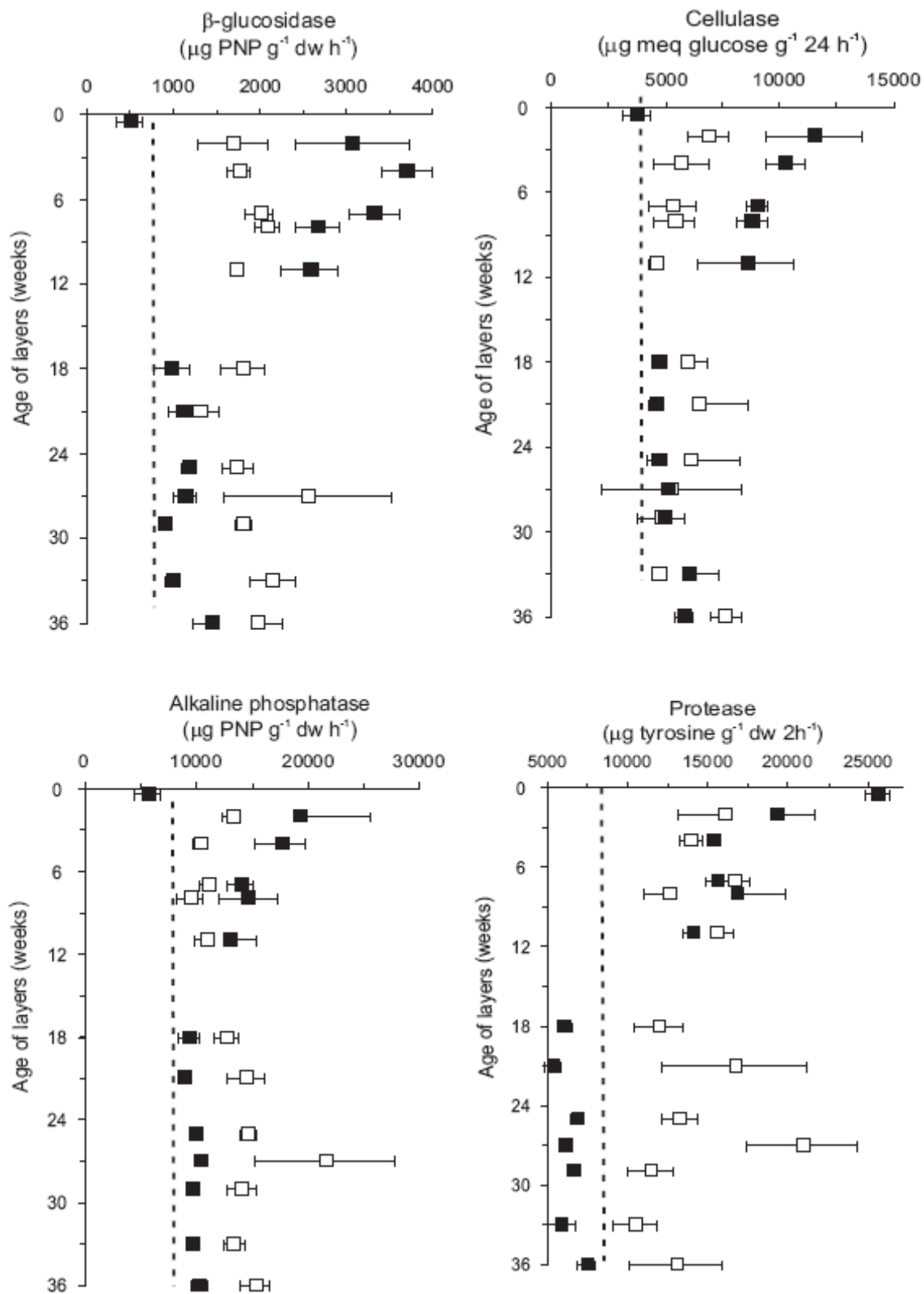


Figure 1. Changes in b-glucosidase, cellulase, alkaline phosphatase and protease activity in reactors fed with pig slurry with (black symbols) and without earthworms (white symbols). The dashed line represents the estimated amount of extracellular enzyme activity (see table 1)

	<i>C_{mic}</i>	Extracellular enzyme activity
β -glucosidase	<i>0.45</i>	
1.5 kg	<i>0.66</i>	760 $\mu\text{g PNP g}^{-1} \text{ dw h}^{-1}$
3 kg	<i>0.49</i>	1080 $\mu\text{g PNP g}^{-1} \text{ dw h}^{-1}$
Cellulase	<i>0.35</i>	
1.5 kg	<i>0.60</i>	3250 $\mu\text{g meq glucose g}^{-1} \text{ dw 24 h}^{-1}$
3 kg	<i>0.48</i>	44900 $\mu\text{g meq glucose g}^{-1} \text{ dw 24 h}^{-1}$
Alkaline phosphatase	<i>0.15</i>	
1.5 kg	<i>0.53</i>	8070 $\mu\text{g PNP g}^{-1} \text{ dw h}^{-1}$
3 kg	<i>0.50</i>	2950 $\mu\text{g PNP g}^{-1} \text{ dw h}^{-1}$
Protease	<i>0.33</i>	
1.5 kg	<i>0.45</i>	7710 $\mu\text{g tyrosine g}^{-1} \text{ dw 2 h}^{-1}$
3 kg	<i>0.14</i>	16160 $\mu\text{g tyrosine g}^{-1} \text{ dw 2 h}^{-1}$

Table 1. Correlations between microbial biomass-C (*C_{mic}*) and the four enzyme activities analyzed.

The first value corresponds to correlation of both rates of pig slurry (1.5 and 3 kg) together, the other two values correspond with the correlation of *C_{mic}* and the enzymes in each rate of pig slurry separately. Values in italics are statistically significant ($p < 0.0001$). We also give the values of extracellular enzyme activity per each rate of pig slurry. To quantify the amount of extracellular enzyme activities we applied the approach of McLaren and Pukite (1973) as in Nannipieri et al. (1996). It consists in plotting the enzyme activity against the microbial biomass and, if the correlation between them is significant, the extrapolation to zero biomass will give the extracellular enzyme activity (Nannipieri et al., 1996; Dilly and Nannipieri, 2001).

Discussion

Earthworms increased microbial biomass during vermicomposting of pig slurry. This increase was related with the initial activation of the four enzymes assayed, mainly via intracellular enzyme activity. We found strong extracellular enzyme activities which remained active through decomposition process; this extracellular activity increased with rate of pig slurry application indicating substrate availability for extracellular enzyme activity. The strong correlation between *C_{mic}* and enzymes, especially in the young layers suggest that there was synthesis of new enzymes, and part of the measured enzyme activity was from intracellular origin (Nannipieri et al., 1996, 2002; Dilly and Nannipieri, 2001), which would have triggered following enzyme activity. Moreover, the ratio between extracellular enzyme activity match with the ratio between overall enzyme activities in layers where earthworm left suggesting a baseline of extracellular enzyme activity during organic matter degradation. Measuring extracellular activity as proposed by McLaren and Pukite (1973) implies the assumption of the non-existence of substances which repress or induce the enzyme synthesis. This may complicate the results in nutrient rich environments like pig slurry, and conclusions have to be taken with care. However, this method has been tested and probed its suitability through a huge amount of soils, including those treated with sewage sludges (Nannipieri et al. 1996).

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Earthworms accelerate cellulose decomposition through the enhancement of fungal biomass during vermicomposting

Manuel Aira¹, Cristina Lazcano¹, Jorge Domínguez¹

Key words: cellulose loss, ergosterol content, cellulase and β -glucosidase activity

Abstract

Here we assess whether the earthworm *Eisenia fetida* (Savigny 1826) digests cellulose directly (i.e. with its associated gut microflora), and also whether the effects of *E. fetida* on microbial biomass and activity lead to a change in the equilibrium between fungi and bacteria. To evaluate the role of *E. fetida* in cellulose decomposition we carried out an experiment in which pig slurry, a microbial-rich substrate, was treated in small-scale vermireactors with and without earthworms. Earthworms doubled the rate of cellulose decomposition, and increased fungal populations which also triggered the production of cellulose enzymes (β -glucosidase and cellulase)

Introduction

Cellulose is the most abundant polymer in nature and constitutes a large pool of carbon for microorganisms, the main agents responsible for organic matter decomposition. Cellulolysis occurs as the result of the combined action of fungi and bacteria with different requirements. Earthworms influence decomposition indirectly by affecting microbial population structure and dynamics, and also directly because the guts of some species possess cellulolytic activity. Here we assess whether the earthworm *Eisenia fetida* (Savigny 1826) digests cellulose directly (i.e. with its associated gut microflora), and also whether the effects of *E. fetida* on microbial biomass and activity lead to a change in the equilibrium between fungi and bacteria. By enhancing fungal communities *E. fetida* would presumably trigger more efficient cellulose decomposition.

Materials and methods

To do this we designed experimental continuous feeding reactors. The reactors were comprised of modules that were added sequentially to the system. The modules, which resembled sieves, were made of PVC - the external diameter of each was 30 cm with a height of 4 cm giving a volume of 2826 cm³. The bottom of the modules was a mesh size 5 mm, which allowed earthworms to move between modules. Each reactor was initially composed of one module containing vermicompost, in which earthworms were placed, and another module containing a layer of 3 kg of fresh pig manure. We set up a batch of six vermireactors, three without earthworms (control) and three containing an initial population of 500 mature earthworms (*E. fetida*) each. At the end of the experiment (i. e. after 36 weeks), the vermireactors comprised 12 modules with an increasing gradient of age, resembling a soil profile, from upper to lower layers as follows : 2, 4, 7, 8, 11, 18, 21,25, 27, 29, 33 and 36 weeks. For sampling, the reactors were dismantled and the modules isolated to avoid the earthworms escaping. The earthworms were then manually removed from the substrate; we found earthworms only in layers of 2, 4, 7, 8, 11 and 18 weeks of age. In order to assess the effect of earthworms on decomposition of pig slurry, we restricted sampling in vermireactors both with and without earthworms (i.e. treatment and control) to the modules corresponding to the above-mentioned times. Five samples of substrate per module were taken at random and gently mixed for biochemical analyses, i.e. cellulose, microbial biomass C (Cmic), ergosterol content, and β -glucosidase and cellulase activities (Alef and Nannipieri, 1998).

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Results

The presence of earthworms in vermireactors significantly increased the rate of cellulose decomposition (0.43% and 0.26% cellulose loss day^{-1} , with and without earthworms respectively, Fig. 1a). Ergosterol content was significantly higher in all layers in vermireactors with earthworms than in those layers of vermireactors without earthworms, with a peak of $75 \pm 22 \mu\text{g g}^{-1} \text{ dw}$ in the 4-week-old layer (Fig. 1b). Enzyme activities (β -glucosidase and cellulase) were also enhanced by the presence of earthworms (Figs. 1c,d).

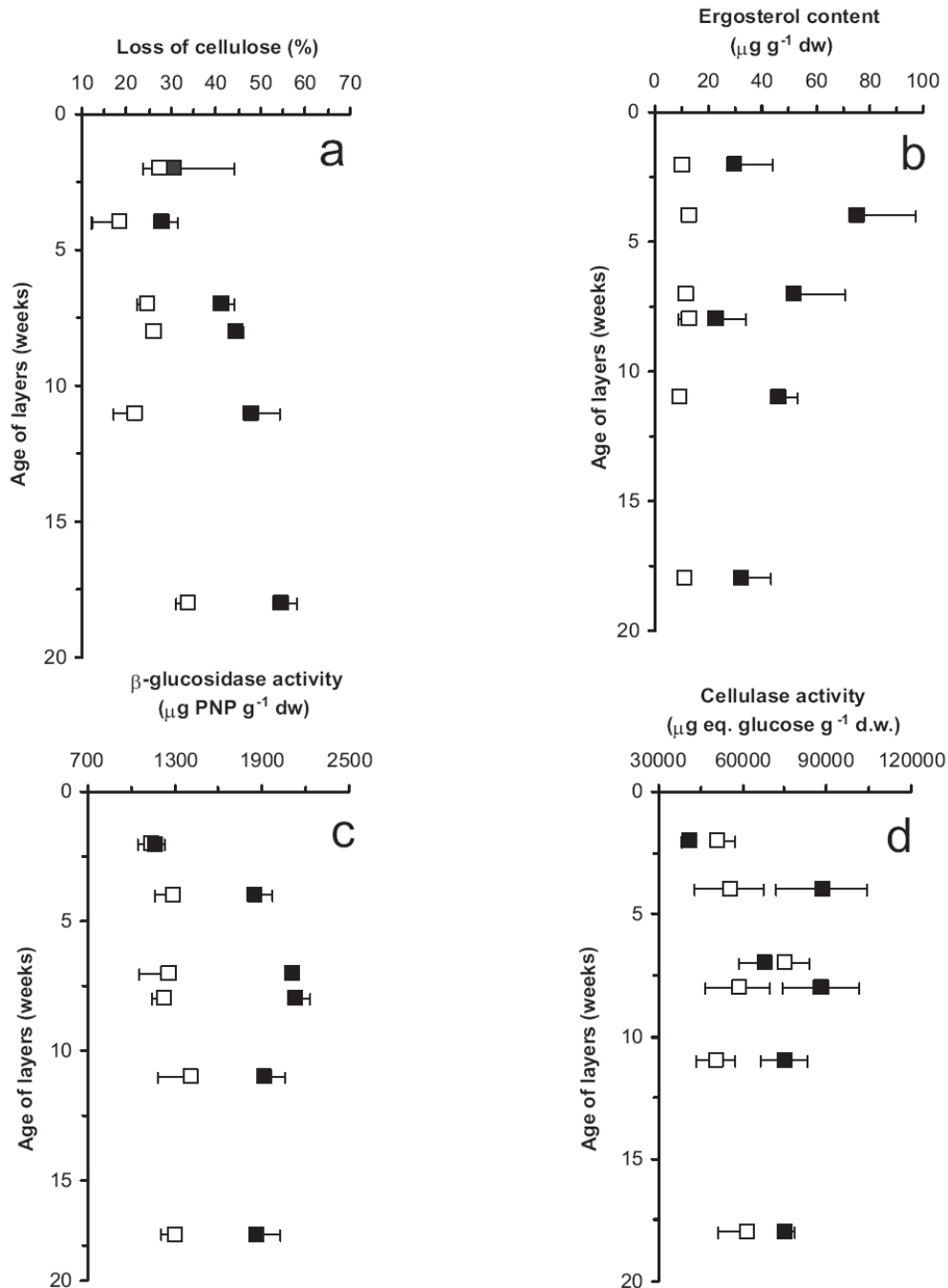


Figure 1: Loss of cellulose (a) and changes in ergosterol content (b), β -glucosidase (c) and cellulase (d) activity in layers of vermireactors with (closed squares, $n = 3$) and without (open squares, $n = 3$) *E. fetida*. The vertical distributions of variable values (mean \pm SE) are shown on the y-axis, i.e. corresponding to age of pig slurry layers, between 2 and 18 weeks.

Discussion

The results of the present experiment indicated that the presence of *E. fetida* in vermireactors clearly favoured cellulose degradation. In vermireactors with earthworms, the rate of cellulolysis was two times higher than in vermireactors without earthworms, resulting in a 1.5-fold increase of cellulose loss after 18 weeks. Similar cellulose loss was reported by Vincelas-Akpa and Loquet (1997) during vermicomposting of pruning wastes with *E. fetida*. Microbial biomass was clearly enhanced in vermireactors with earthworms, although it is generally assumed that microorganisms, especially fungi, are supposed to be an important part of the earthworm diet (Edwards, 2004). Despite of this, fungi biomass was enhanced by earthworms, which was associated with an activation of enzyme activities leading to a more efficient cellulose decomposition.

Conclusions

We found that the earthworm *Eisenia fetida* promoted fungal growth and production of microbial enzymes involved in cellulolysis during vermicomposting of pig slurry. We suggest that this activation is a key step leading to more intense and efficient cellulolysis during vermicomposting of organic wastes.

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Role of microorganisms during aging of vermicompost: effects of decaying enzyme activity.

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Key words: vermicomposting aging, enzyme activity, vermicompost quality, microbial stabilization, enzyme protection

Abstract

In the present study, the effects of vermicompost aging and especially the patterns of changes in microbial biomass and enzyme activities during aging were investigated because these parameters can control the quality of the resulting vermicompost. We incubated 16 week-old vermicompost (fresh vermicompost) and sampled it after 15, 30, 45 and 60 days analyzing microbial biomass and activity and four enzymatic activities. Aging of vermicompost resulted in decreases of microbial biomass and activity. Three of the four enzymes analyzed also showed decreased values.

Introduction

Vermicomposting is the biooxidation and stabilization of organic matter involving the joint action of earthworms and microorganisms, thereby turning wastes into a valuable soil amendment called vermicompost. Studies have focused on the changes in the type of substrates available before and after vermicomposting, but little is known on how these changes take place, especially those changes related with maturation of vermicompost (Domínguez, 2004).

Materials and methods

Samples of vermicompost (1 kg fresh wt.) from five vermireactors were placed separately in five plastic trays (60 3 40 3 10 cm) and maintained at a constant temperature (20°C) in a laboratory chamber. The five vermireactors were set up at the same time in a room with constant temperature (208C), and each sampling time represented the same aging time for each vermireactor (16 week old). The modules of vermireactors corresponding to 16-wk-old substrate were sampled because they were the first modules containing no earthworms. Samples from these plastic trays were taken at 0 (16-week-old vermicompost), 15, 30, 45, and 60 days. We analyzed microbial biomass-N, basal respiration, β -glucosidase, cellulase, protease and alkaline phosphatase (Alef and Nannipieri, 1998)

Results

Aging of vermicompost resulted in decreases of microbial biomass and activity (Fig. 1). Three of the four enzymes analyzed also showed decrease (Fig. 2abc). An initial increase followed by a rapid decrease in alkaline phosphatase was also recorded (Fig. 2d). High and significant correlations between microbial biomass and β -glucosidase ($r = 0.62$, $P < 0.001$), cellulase ($r = 0.56$, $P < 0.01$) and protease ($r = 0.82$, $P < 0.001$) were found.

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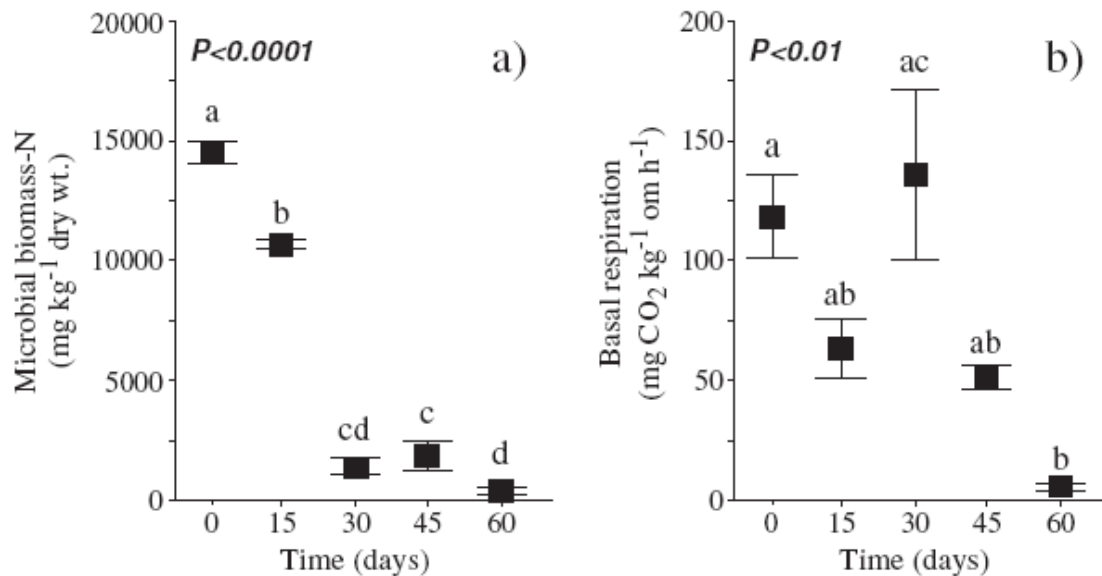


Figure 1: Changes in (a) microbial biomass N (mean \pm S.E.) and (b) basal respiration during incubation of vermicompost (n = 5). Different letters indicate significant differences at $p < 0.05$ (Tukey HSD) (dry wt. = dry weight; om = organic matter).

Discussion

The results of this study showed that once earthworms have left the organic waste, the process of aging of vermicompost is mainly characterized by microbial processes which experience a continual decrease as indicated by microbial biomass N, basal respiration, and some of the enzyme activities measured, as usually occur when processing organic wastes with earthworms (Edwards, 2004). Despite different dynamics of aging shown by the four enzyme activities, one of the characteristic findings was that, independently of the previous values reached, the lowest values were recorded in the vermicompost incubated for 60 d, suggesting the existence of a threshold for microbial survival and metabolism which may have affected extracellular enzyme activity. This hypothesis is strengthened by the highly significant correlations found between microbial biomass and three of the enzymes analyzed (β -glucosidase, cellulase, and protease).

Conclusions

Our results suggest that there may be two steps involved in the aging dynamics of vermicompost with regards to extracellular enzyme activity; the first step was characterized by a decrease in microbial populations, which resulted in a reduction in the synthesis of new enzymes. The second step was the degradation of the pool of remaining enzymes. This dynamic does not seem to be affected by earthworms because similar decaying patterns of microbial biomass and activity were found in substrate where earthworms were present.

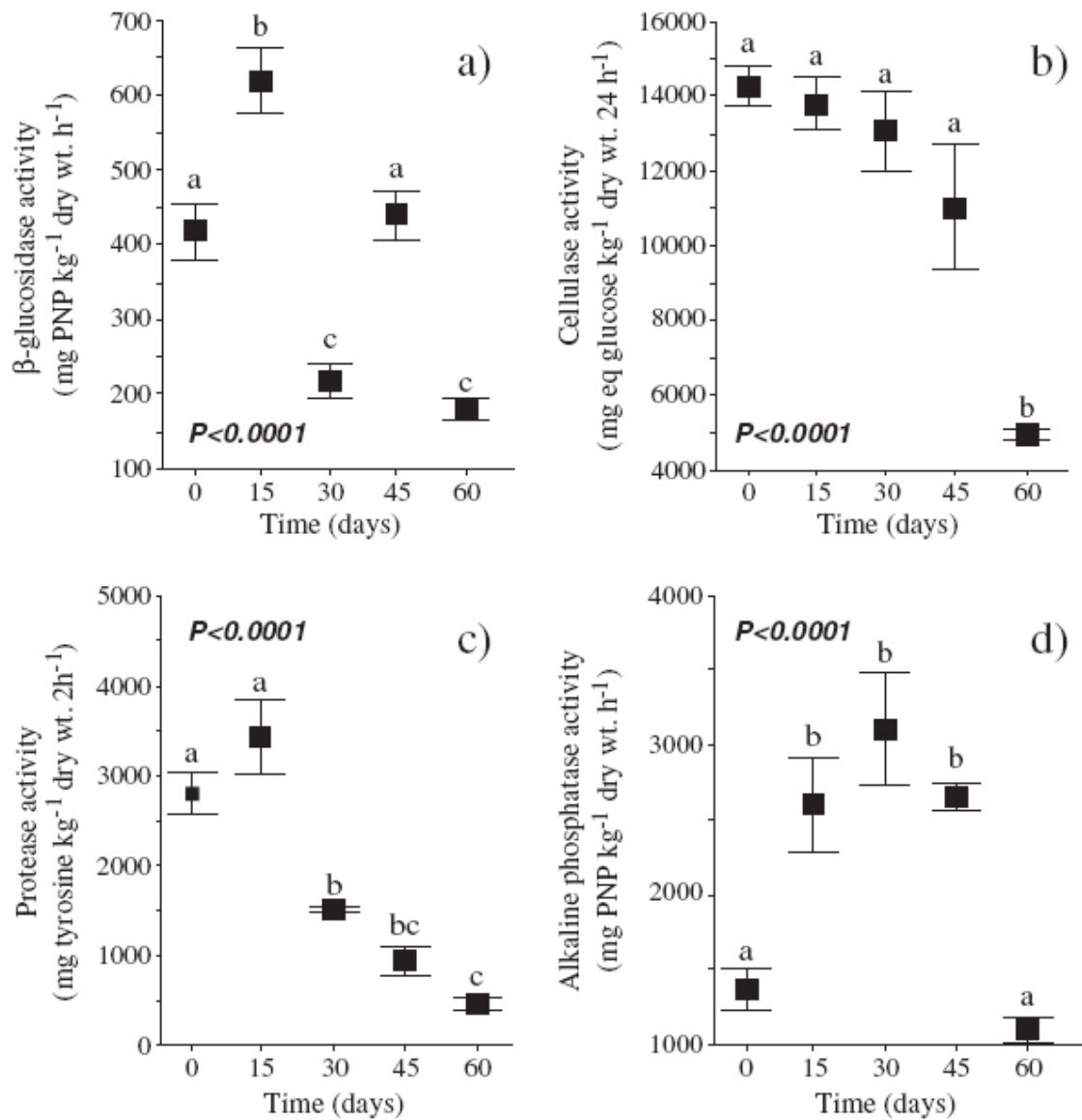


Figure 2: Changes in (a) β -glucosidase (mean \pm S.E.), (b) cellulase, (c) protease, and (d) alkaline phosphatase during incubation of vermicompost (n = 5). Different letters indicate significant differences at $p < 0.05$ (Tukey HSD) (dry wt. = dry weight; PNP = *p*-nitrophenol).

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Microbial community changes during the vermicomposting of grape marc

Maria Gómez-Brandón¹; Cristina Lazcano¹, Marta Lores², Jorge Domínguez¹

Key words: Vermicomposting; Grape marc; PLFAs; Biolog Ecoplate; Microbial communities

Abstract

We studied the changes in the structure and physiological capabilities of the microbial community during the vermicomposting of grape marc analyzing the profiles of phospholipid fatty acids and the community-level physiological profiles, respectively. We found that both techniques were sensitive enough to discriminate both treatments with and without earthworms and also those from the initial grape marc. This fact evidences that earthworms were able to modify the structure and the functional diversity of the microbial community of grape marc.

Introduction

Grape marc is a valuable resource as a soil fertilizer (Flavel et al., 2005); however, the overproduction of waste products by winery industry has led to their direct and indiscriminate application to agricultural fields which could cause adverse effects on plant roots growth due to the release of tannins and phenols. These problems could be overcome by treating winery wastes by aerobic biodegradation processes such as composting and vermicomposting before their disposal or use. Vermicomposting depends on the joint action of earthworms and microorganisms; although earthworms are the main drivers of the process, microorganisms are responsible for the biochemical degradation of the organic matter. Therefore, the characterization of microbial communities would clearly improve the understanding and development of this process. Recently, several methods for addressing community-level characteristics have been developed including the analysis of phospholipid fatty acids (PLFAs) and the community profiling based on sole carbon source substrate utilization (BIOLOG Ecoplate). This last technique is relatively simple, fast and can provide a valuable insight into the functional aspects of organisms (Garland, 1997). PLFAs are the major constituents of all living cells membranes and some PLFAs are considered as biomarkers for specific microbial groups (Zelles, 1999). Thus, the main objective of this study was to describe the shifts in the microbial community structure and function based on PLFAs and BIOLOG profiles during the vermicomposting of grape marc.

Materials and methods

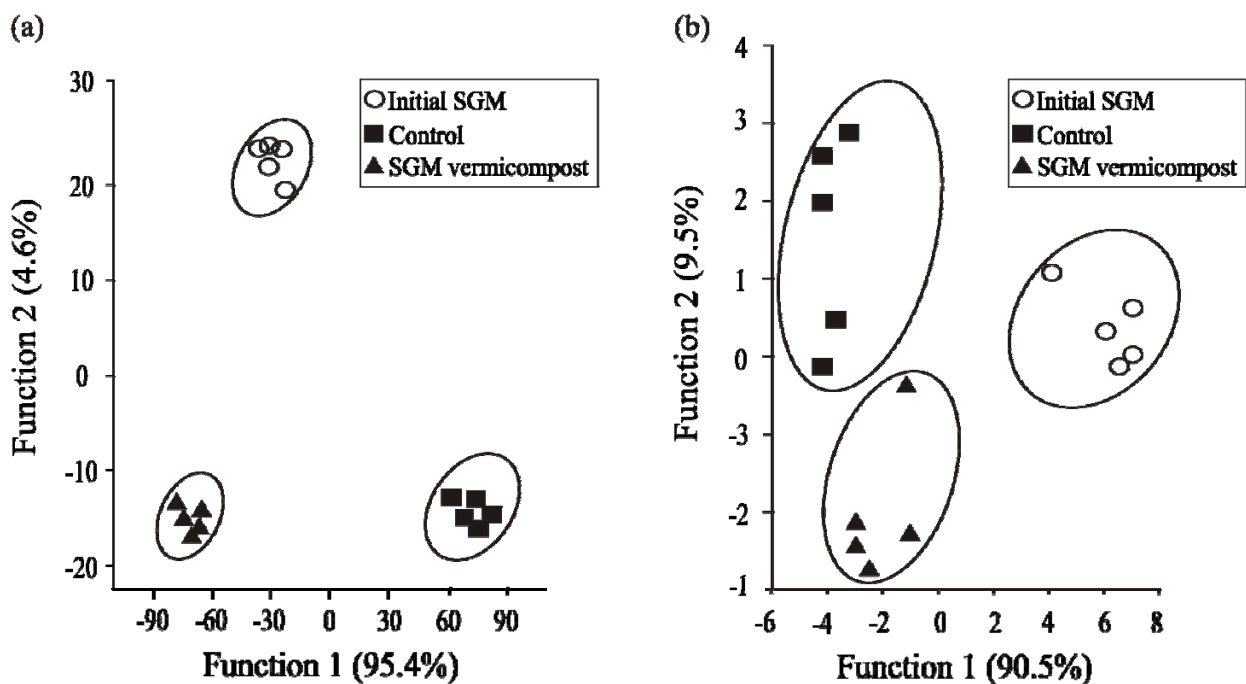
The initial grape marc was turned and watered until the earthworms were capable of eating it. Then one kg of grape marc was introduced into each of ten plastic containers. Specimens of the earthworm *Eisenia andrei* (250 g per container) were added into five of the containers, while the other five remained without earthworms and served as controls. The containers were maintained at 25 ± 2 °C and 90% relative humidity in a scientific incubator and after 15 days, earthworms were removed and control and grape marc vermicompost samples were collected and sieved for analysing. Five replicates of the initial grape marc were also analysed for comparison.

Results

Discriminant function analyses performed on the identified carbon sources clearly differentiated the treatments with and without earthworms, and those from the initial grape marc (Figure 1a) using two substrate guilds (polymers and miscellaneous). The discriminant analysis performed on the identified PLFAs also clearly separated the samples (Figure 1b) with two PLFAs (17:0 and a15:0).

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Carbon sources	Standardized Canonical Function Coefficients	
	1	2
Polymers	2.797	1.006
Miscellaneous	-4.813	2.495
(Constant)	1.780	-7.699

Fatty acid	Standardized Canonical Function Coefficients	
	1	2
17:0	-15.956	42.145
a15:0	12.793	-1.585
(Constant)	-2.927	3.135

Figure 1: Discriminant function analyses of (a) Biolog carbon sources and (b) PLFA profiles for the initial grape marc, control and vermicompost samples. The variance explained for each function is given in parentheses.

Discussion

Despite the fact that Biolog only selects the fastest growing portion of the microbial community (Smalla et al., 1998), the present study showed that earthworms were able to modify the functional diversity of microbial populations as revealed the discriminant analysis performed on the Biolog carbon sources. Moreover, PLFA analysis was sensitive enough to discriminate the samples, providing evidence of distinct PLFA composition in both treatments with and without earthworms and also with respect to the initial grape marc. Therefore, earthworms not only altered the functional diversity of the microbial community of grape marc, but also modified its structure.

Conclusions

The present study demonstrated the power and sensitivity of both techniques, which allow us to broad our knowledge about how the earthworms modify the structure and function of microbial communities during the vermicomposting process.

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The experimental modelling of interactions on some organic materials with mineral components of horticultural soil conditioned with polymeric materials

(I). Preliminary results

Feodor Filipov¹, Dumitru Bulgariu^{2,5}, Gerard Jităreanu¹, Laura Bulgariu³, Gabriela C. Chițanu⁴

Key words: compostation, horticultural soil, green polymers

Abstract

In this study are presented the preliminary results obtained by experimental modelling of interaction between organic compounds and mineral components of one horticultural soil sample, conditioned with three types of polymers: polyethylene glycol, vinyl acetate – ammonia maleate salt copolymer and methylacrylate – ammonia maleate salt copolymer. The effects of polymers on decomposition processes of organic materials in horticultural soils conditions are concretized in: (i) increasing of initiation duration for decomposition processes; (ii) decreasing of relative decomposition degree for organic materials; (iii) the ratio decrease and the limitation of decomposition possibilities for organic materials; (iv) increase of relative mineralization degree of organic carbon; (v) the limitation of formation and extension ratio of compact and impermeable horizon (possible frangipane), responsible in most cases, by degradation of horticultural soils.

Introduction

The utilization of intensive technologies for plants cultivation in glass houses by the administration of high doses of organic fertilizers, the realization of supra-dimensioned irrigation and the maintain of soil at a high humidity state, determined the fast degradation of morphological, physical and chemical properties of these. The conditioning and the amelioration of horticultural soils with ecologic polymers is one of the method approved in this moment and according with most the opinion, represent one of method with large applications in modern agriculture. The our studies realized by experimental modelling on interaction of some organic materials (corn straws, corn cobs, sawdust) with mineral components of horticultural soil, conditioned with different polymers, completed by the field observations obtained in glass houses from Iași and Bacău cities, have evidenced a particular evolution of organic matter, a distribution and interaction way respectively, with soil components.

Materials and methods

For the experiments, a horticultural soil sample (Aho1 horizon) was used, from “Copou” glass house perimeter, Iași city, Romania. Before the mixing with organic material, the soil sample (< 1.00 mm) was pre-incubated at 20°C, at approximate constant humidity (55-60 kPa), time of 7 days. As organic amendments corn straws, corn cobs and sawdust was used. For work was used a mixture obtained from equal parts from the three components (< 1.00 mm). For soil conditioning, three types of water-soluble polymers have been used: polyethylene glycol (M.W.=1550), vinyl acetate – ammonia maleate salt copolymer and methylacrylate – ammonia maleate salt copolymer. Before to start the experiments, both soil samples and organic materials mixture have been analyzed, chemical, physical and mineralogical, by usual methods described in literature. The organic material mixture was homogenous incorporated in horticultural soil sample in normal stage of humidity. The mixing ration was 1 part of organic material mixture and 5 parts of horticultural soil. The obtained mixture was placed in the reactor of experimental installation, where has been treated with 10 mL of 5 % polymer aqueous solution. The decomposition process was follow during of 40 days. In this time interval have been periodical monitoring the temperature from solid phase and the volatile decomposition products flow, eliminated from experimental installation (CO₂, H₂S, NH₃, nitrogen oxides, sulphur oxides, etc.).

Results

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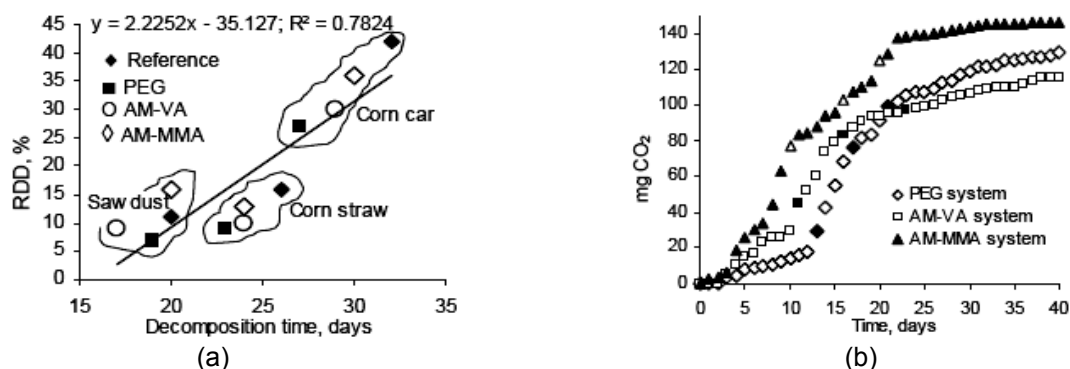


Figure 1: The dependence between the relative decomposition degree of organic materials (RDD, %) and effective decomposition time (a). The cumulative curve of CO₂ evolution (mg CO₂), for the systems with polymers, in function of time.

Discussion

The organic mater decomposition in hortc antrosoils occurs more fast than in case of other soil type. In consequence, the input flux of organic compounds in soil is higher and the diversity of formed chemical compounds is higher. This determined a fast and intense perturbation of equilibriums from soil, the destabilization ratio being superior to re-adaptation (equilibrium) ratio of soil, which is reflected by a fast and intense degradation of morphological, physical and chemical characteristics. The polymers used for antrosoil conditioning, controlled most probable the kinetics of organic material decomposition processes and less the thermodynamic of these, but these effects are dependent by the physic-chemical properties of polymers and the used doses. In comparison with the blank system, in the systems with polymers the thermal effects associated with the organic materials decomposition is not significantly different, but the decomposition degree (figure 1.a) and the processes ratio, decrease. In consequence, in systems with polymers, the organic carbon losing (estimated as CO₂ – figure 1.b) are significant diminished, and the formation and extension ratio of compact and impermeable horizon, responsible in most cases, by degradation of hortc antrosoils is more attenuated. These effects are more intense and longer in case of polymers with higher hydrophobicity and hydrolytic stability.

Conclusions

The effects of polymers on decomposition processes of organic materials in hortc antrosoils conditions, are concretized in: *(i)* increasing of initiation duration for decomposition processes; *(ii)* decreasing of relative decomposition degree for organic materials; *(iii)* the ratio decrease and the limitation of decomposition possibilities for organic materials; *(iv)* increase of relative mineralization degree of organic carbon; *(v)* the limitation of formation and extension ratio of compact and impermeable horizon (possible frangipane), responsible in most cases, by degradation of hortc antrosoils.

Acknowledgments

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Poster presentations session P3

Impact of home made composts application at maize cultivation

Milena S. Stoichkova¹

Key words: composting, home made composts, organic manures, fertilization, maize cultivation

Abstract

*Because of the insufficiency of traditional organic fertilizers during the last years it is necessary to search for new sources of organic matter. One of the most accessible and really realizable forms of the domestic wastes use is their transformation into compost, a process, known as home (family) composting. The aim of this work was: to make a comparatively studying of the effect of composts, produced by home composting and other organic manures on the maize growth and weeds appearance. The vegetation experiment was carried out in vessels from 2 kg, with soil – *Iuvic phaeozem*/FAO, culture –maize and different organic fertilizers: cattle, poultry and sheep manure and composts, made with suitable agrochemical indices from different organic domestic wastes. Phenological observations and measuring were periodically made. The study shows, that using of home made composts is equivalent to that of manures, regarding to their effect on the vegetative behaviour of maize. Using of composts leads to decrease of weeds, because of the thermophilic (sanitarisation) phase during the composting process. The organic matter from home made composts, added to the soil, has the potential to control many soil-borne plant pathogens.*

Introduction

In most of the member states drastic measures will become necessary to comply the required limit values of biodegradable wastes in landfills within the given time frame (2006 - 2016) according to the EU directive. Composting of domestic wastes decrease their collecting on depot and reduce hazards and emissions from landfill sites. The high-quality composts have a positive effects on plant growth and health. They influence plant development by an improved soil structure and an elevated soil humus content as well as by supplying macro- and micronutrients (Zebarth et al., 1999; Fuchs, 2000). Although numerous reports concerning application and environmental impact of composts, little is known about the influence of home made composts application. The objective of the present work was to study the potential of home made composts application at maize cultivation and to compare them with other organic manures.

Materials and methods

The experiment was carried out in vessels from 2 kg, with soil – *Iuvic phaeozem*/FAO, culture –maize and different organic fertilizers: cattle, poultry and sheep manure and composts - produced during the composting of the organic fraction of source separated household wastes (i.e. vegetables, fruits and garden wastes, coffee sludge, egg shells). Two different bins were used for composting – closed (200 l) and open (600 l), which were filled in the same way. The initial C/N ratio of the mixtures was 25/1. The bins were not regularly fed with fresh wastes. During peak heating, the temperatures increased to 65°C in the closed and to 60°C - in the open bin and kept high for 10 days. The piles were turned regularly to achieve thorough heating of all parts of the waste, is efficient enough to eradicate plant pathogens. The moisture content was 55-60%. Germination tests with radish and cress seeds were made in 200-ml plastic pots, after 120 days composting. Both of composts (produced in closed and open bins) had germination rate higher than 80%. Before starting the experiment, agrochemical analyses of the soil and the organic manures were made. The trial was carried out in 7 variants (with 5 replicates): 1. Control (only soil); 2. Control (soil + mineral fertilizers: N- 200 mg/kg, P₂O₅ -150 mg/kg, K₂O-150 mg/kg, like NH₄NO₃, CaH₂PO₄ and K₂SO₄); 3. Soil + cattle manure; 4. Soil + poultry manure; 5. Soil + sheep manure; 6. Soil + compost 1 (produced in the closed bin) and 7. Soil + compost 2 (produced in the open bin). The amounts of organic manures were equalized in their total nitrogen content (200 mg N /kg). After sowing of maize seeds, observations and measuring were periodically made. The trial was done to phase 10 -12 leaf. The statistical program *statgraph* was used at results treatment.

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Results

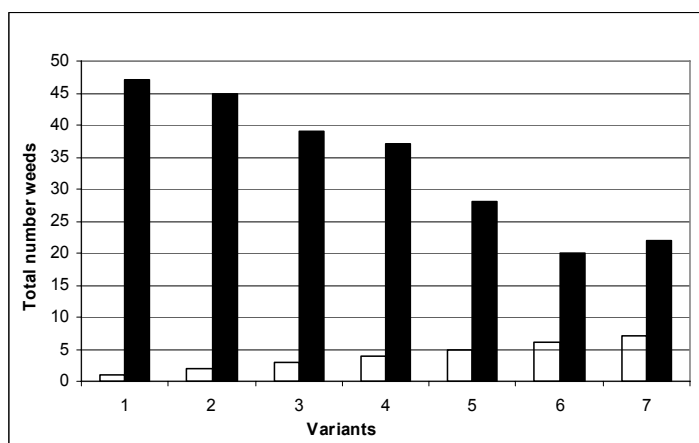


Figure 1: Total number of weeds in the different variants.

Tab. 1: Values of the biometrical measuring and yield.

Variants	Height of the plants (after two weeks of sowing)	Height of the plants (after two weeks of sowing)	Yield (g dry mass)
1.	24 bc	50 a	9,86 a
2.	25 d	84 fg	28,85 l
3.	24 cd	73 bc	16,38 ef
4.	24 cd	85 fd	22,28 hi
5.	23 bcd	78 de	19,08 g
6.	24 cd	80 ef	23,45 ik
7.	23 bcd	91 h	25,68 k

* The least significant differences (LSD) are symbolized with different letters at 95% confidential level.

Discussion

The figure 1 shows that the total number of weeds is smallest in the variants with composts due to eradication of pathogens from household organic wastes. The most important reason for that is the heat generated during thermophilic phase of composting (Hoitink and Fahy, 1986). The variant with compost, produced in closed bin contains less weeds than the other one, probably because of the higher temperature in the closed bin. Initially the variant with mineral fertilizers has highest plants but at the second date the variants with composts and other organic manures do not differ from it in plant height. The reason for that is slower and gradual mineralization of organic substances. The amount of dry mass (yield) is biggest in variant 2 (with mineral fertilizers), 6 and 7 (with composts participation) i.e. home made composts contain sufficient amount nutrients, required for plant development.

Conclusions

The utilization of home made composts is equivalent to that of manures, regarding to their effect on the vegetative behaviour of maize. One of the major benefits from composting is the destruction of weed seeds and pathogens through elevated temperature. The composts from household organic wastes are contaminant free and are suitable for maize cultivation.

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Evaluation of Composted Cattle Slurry Fibre as Peat Diluent

Munoo Prasad¹

Key words: storage, peat diluents, CAT nutrient levels, storage, plant growth, growing media

Abstract

Fibre extracted from cattle slurry was used in this experiment. The fibre was composted for 12 weeks, either on its own (CS) or mixed with peat (CSP) 50:50 or mixed with sawdust (CSS). At the end of the compost phase two compost material was mixed with peat at a rate of 10%, 20% and 30% (at 20%, 40% and 60% for CSP) and stored in bags for 434 days. Samples were taken at the start and 5 times during 434 days. The samples were then analysed using the CAT method. The pH dropped while EC increased during storage. Extractable N also increased moderately indicating no N immobilization. A plant growth trial at the end showed there was difference between the compost materials and increasing rates generally showed better growth. However there was also a significant interaction.

Introduction

There is increasing pressure from the environmental lobby particularly in the UK to reduce the use of peat in horticulture. Alternatives such as composted bark or coir can indeed replace peat to 100%; however the quantity of processed material available is insufficient to replace peat. Composted greenwaste is a very good candidate to peat dilution (Prasad & Carlile 2006, in press), but one of the problems when used for peat dilution for the export market is the weight of the composted greenwaste. In Ireland there is a government policy to separate out the fibre from the slurry and store the liquid component and apply the liquid into the land at an appropriate time. The fibre is a light weight material and is therefore very attractive. Limited work done in this area by Chen et al., 1986 in Israel has shown this material when composted can be used as a growing media. However there has been little or no work done with this material in Western Europe particularly as a peat diluent. Consequently we carried out a composting trial for its use as a peat diluent.

Materials and methods

A sample of fibre which had been separated from cattle slurry of the following concentration was used in the trial, N = 1.63, P = 0.34, k = 2.49 and C:N ratio of 30. The slurry fibre was composted on its own (CS), or mixed with peat at 50:50 (CSP) or mixed with sawdust (CSS). Extra N was added to bring C:N ratio to 20. They were composted for 12 weeks with a volume of 40m³. During the period, it was turned regularly (3- 5 times a week) and temperature and CO₂ were measured regularly.

At the end of the composting the analysis was SS, pH 8.73, EC 2840cm⁻¹, SSP pH 6.75, EC 1345cm⁻¹ and SSS pH 8.02, EC 1560cm⁻¹ in 1:15 water extract. They were then mixed with peat at a rate of 10, 20 and 30% except for CSSP which was double the amount to have the same peat content in the product before the storage experiment and then bagged (20 litre). They were stored at room temperature for 434 days. Samples were taken at 0, 10, 31, 110, 246 and 434 days. Nitrogen was added to bring the extractable N to around 200mg/L in all treatments.

Results

After 434 days of storage there was a drop in pH when CS was added to the peat but less so with CSP and CSS. In contrast the pH of the peat increased initially and then remained very stable. The EC increased as the storage time increased and was most pronounced in CSP but EC levels were highest in CS. As a result of nitrification, by 100 days almost all NH₄-N had nitrified. Nitrification was most rapid in CSP compost. In contrast in 100% peat took longest to nitrify. Extractable Nitrogen (NH₄-N + NO₃-N) increased moderately in all compost treatments and was most marked in CS (Fig 1). There was a slight increase in P at 110 days but K remained very constant during storage. Increasing rates (10%, 20% and 30%) increased nutrients in all peat compost mixtures.

Fresh weight of tomato plants were highest in CSS followed by CSP and CS ($p < 0.084$). Increasing rate increased fresh weight ($p < 0.031$) but there was a significant interaction (Fig 2). All treatments performed as good as or better than peat. There was no significant correlation between any of the nutrients and fresh weight when all the treatments were lumped together. However individually in each

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mixture with increasing rate of compost application N, P and K content increased as well there was an increase of fresh weight of tomato plants of CSS and CSP but not CS.

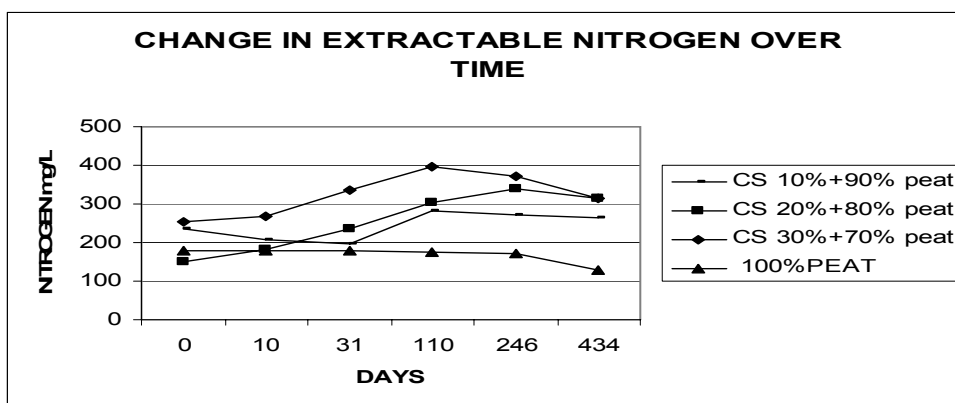


Figure 1: Change in extractable nitrogen over storage time

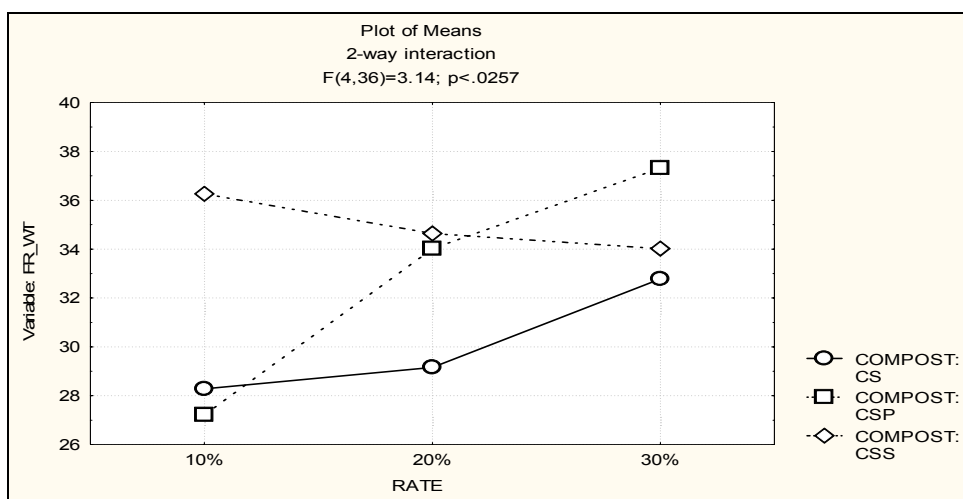


Fig 2: Fresh weight of tomato seedling as affected by compost and rate of application. (Peat control gave a fresh weight of 26g)

Conclusions:

These results showed clearly the potential of composted slurry fibre as a suitable peat diluent.

Acknowledgments.

Thanks are due to Colman Hynes and Dearbhail Ni Chualain for their excellent technical support.

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Ecotoxicity of Hydrocarbon-Contaminated Soil Remediated by Vermicompost Tea

Daniel Lesinsky¹, Veverka, M.

Key words: vermicompost, compost tea, soil remediation, ecotoxicity

Abstract

Elutriate was produced from vermicompost under specific conditions – aerated vermicompost tea (ACT). This medium, rich on micro-organisms and water soluble nutrients was applied on strongly contaminated site by hydrocarbons for 12 month. Ecotoxicity of the contaminated soil samples was analysed by different methods. Results showed evident improvements of the ecotoxicity in most samples (daphnia and duckweed tests).

Introduction

Vermicompost is compost made by earthworms. It has a rich microbial diversity and contains substances, which are beneficial for plant growth. Water elutriates – Compost tea (Scheuerell, 2004) could be used to enhance plant condition and soil fertility. Aerated vermicompost tea (ACT) with additives is recommended to be produced (Ingham, 2006) to enhance the growth of beneficial and suppress pathogenic micro-organisms.

The main objective of this paper is to find out the influence of ACT on ecotoxicity of hydrocarbon-contaminated soil in remediation process. The main assumptions were that micro-organisms in ACT would speed up the remediation process.

Materials and methods

Aerated vermicompost tea was produced in an extraction vessel with the volume of 850 litres from 10 litres compost.

Research was performed on soil that was intensively contaminated by hydrocarbons (25 – 33 mg of non-polar extractives per gram of soil). The site was at a landfill of liquid industrial waste. Waste hydrocarbons from wood impregnation were landfilled here many years ago.

Two experimental sites were marked in area of 4 m². The first site B-1 was watered by tap water (a blank). The second one was in parallel watered by the same volume of ACT – 15 l/m². Application of water/ACT was performed overall 7 times, approximately once per 1 – 2 months, from September 2006 to September 2007, during vegetation period only.

Each soil sample was taken from 5 points of the site, from the depth of 5 – 10 cm. An average sample was done subsequently by homogenisation process. Samples were taken before the first application of the ACT/water on 5th September 2006 and after the last application on 17th October 2007.

Ecotoxicity of samples was measured as an indicator of remediation. Ecotoxicity tests were performed by cress (*Lepidium sativum*), according to OECD guidelines 208 “Terrestrial Plant, Growth Test”; duckweed (*Lemna minor*) according to ISO/CD 20079 “Duckweed Growth Inhibition Test” and daphnia (*Daphnia magna*) according to OECD guidelines 202 “Daphnia sp., Acute Immobilisation Test”.

Results

There is an evident proof of ecotoxicity decrease due to ACT application after the period of 12 months under external conditions at the contaminated sites by hydrocarbons. The ecotoxicity of the contaminated substrate decreased to the non-quantifiable level monitored by *Daphnia magna* (Fig. 1 and 2) and *Lemna minor* (Fig. 3 and 4). Ecotoxicity determined by *Lepidium sativum* was reduced from EC₅₀ = 0,061 to EC₅₀ = 0,110.

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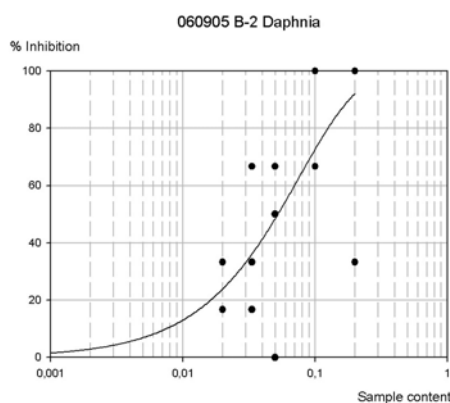


Fig. 1: Ecotoxicity of hydrocarbon-contaminated soil before the first application of ACT, determined by *Daphnia magna*. $EC_{50} = 0.0522$

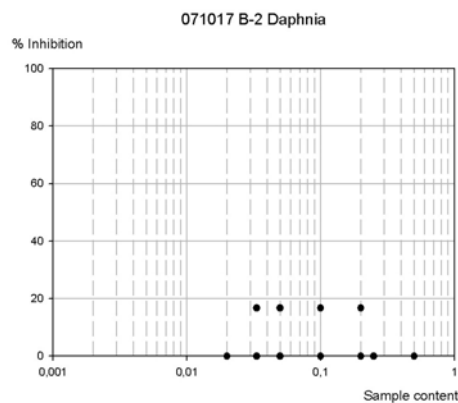


Fig. 2: Ecotoxicity of hydrocarbon-contaminated soil after all applications of ACT, determined by *Daphnia magna*. $EC_{50} = \text{n.d.}$

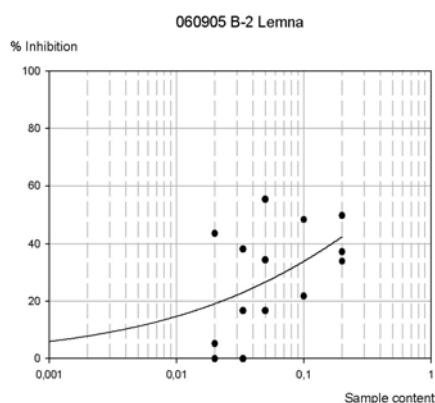


Fig. 3: Ecotoxicity of hydrocarbon-contaminated soil before the first application of ACT, determined by duckweed (*Lemna minor*). $EC_{50} = 0.3439$

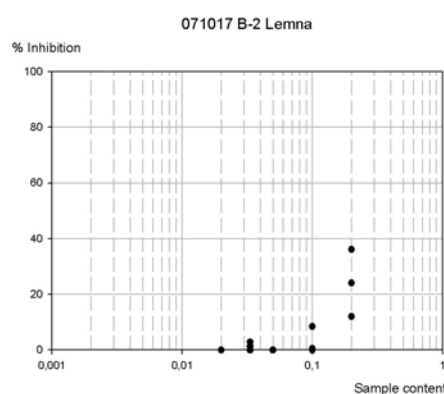


Fig. 4: Ecotoxicity of hydrocarbon-contaminated soil after all applications of ACT, determined by duckweed (*Lemna minor*). $EC_{50} = \text{n.d.}$

Figures 1 – 4: Influence of ACT on the ecotoxicity of the contaminated soil samples determined by *Daphnia magna* and *Lemna minor*.

Conclusions

Aerated vermicompost tea has proved its positive impact in the remediation process of soil site contaminated by specific hydrocarbons pollutants with high concentration. Results were reached under external conditions, thus they are applicable in broad practice. However, it is necessary to prove or specify a positive impact of ACT on the different (hydrocarbon) contaminations and it seems to be necessary to develop also the methodology enabling transport of ACT for longer time or distances. Therefore we strongly advise to follow up this research by investigating the answers for both problems opened above and looking for broader application of ACT in practice.

Acknowledgments

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Comparison

All conventional processes for treatment of organic waste such as landfills, incineration or composting have their drawbacks. On the other hand, treating them with the aid of Kompogas offers numerous advantages. For example, the end products obtained are CO₂ neutral fuel, gas, electric power and heat.

Process description

To produce energy from yard and kitchen waste, biogenous waste is first freed of foreign matter and then fed to the fermenter. In the entirely enclosed reactor operating according to the anaerobic principle (with absence of oxygen), microorganisms transform the organic substance present in the material into compost and biogas. The thermophile fermentation process takes place at a temperature of 55 to 60 degrees Celsius and lasts for 15 to 20 days. In the process, undesirable rootlets and weed seeds are eliminated reliably.

CO₂ neutral energy

The Kompogas plants operated to date receive biogenous waste on a daily basis which is utilised with an optimal energy yield. The biogas produced during waste decomposition is transformed into electrical and thermal energy, ensuring self-sufficient operation and supplying a considerable energy surplus. As an alternative or in combination, the biogas can be upgraded to natural gas standards for the CO₂ -neutral operation of vehicles or it can be fed into the natural gas network. Depending on the specific composition of the biogenous waste, between 105 and 130 cubic metres of biogas are produced per ton. This corresponds to about 70 litres of petrol. Kompogas (biogas), which can be used as a fuel for vehicles or for co-generation units in order to generate electric power, is today considered to be one of the most environmentally friendly, CO₂ -neutral sources of energy available to a broad segment of the population.

Compost, liquid fertiliser

The high-quality, hygienic compost is used by private individuals, in agriculture and in gardening. Fresh Kompogas compost* is a valuable, natural fertiliser allowing impressive harvest results to be achieved.

*Certified for organic agriculture (FiBL)

For further information please contact:

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8152 Glattbrugg
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info@kompogas.ch
www.kompogas.ch

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Rufen Sie uns für ein unverbindliches Angebot an. Kontaktpersonen sind:

Christoph Peter 052 722 46 60 / 079 438 59 02 christoph.peter@rom.ch

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This proceedings volume contains the papers presented at the CODIS 2008 congress held on 27 - 29 February 2008 in Solothurn (Switzerland).

The composting and digestion of biogenic waste materials and the subsequent application of compost and digestate to soil contributes to nutrient recycling and renewable energy production. Moreover, compost and digestate can improve soil fertility and suppress plant diseases. On the other hand, compost and digestate may also contain a variety of pollutants hazardous to soil, such as heavy metals and organic contaminants. Compost and digestate have been thoroughly investigated in the framework of two associated projects entitled "Organic Pollutants in Compost and Digestate in Switzerland" and "Effects of Composts and Digestate on the Environment, Soil Fertility and Plant Health". These projects yielded new insights into the properties of compost and digestate, mainly with regard to biological parameters and the occurrence of both "classic" and "emerging" organic pollutants.

The CODIS 2008 congress was the final event of these two projects.

For more information, see **www.codis2008.ch**