Soil Biology & Biochemistry 57 (2013) 794–802

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Effects of fertilization with urban and agricultural organic wastes in a field trial – Waste imprint on soil microbial activity

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A R T I C L E I N F O

Article history:
Received 12 April 2011
Received in revised form
23 February 2012
Accepted 26 February 2012
Available online 14 March 2012

Keywords:
Microbial activity
Field trial
Sludge
Compost
Organic waste

A B S T R A C T

In the past decades a significant change in composition of urban organic waste products has occurred in many first world countries, due to cleaner technologies as well as outsourcing of heavy industries. However, the societal perception of organic urban waste has become increasingly negative, leading to widespread advocacy of incineration. Therefore we established the 'CRUCIAL' long-term field trial in 2003, with the rationale that by approaching the known limits for a number of heavy metals below which no profound disturbance should be observed on key soil ecological functions, it should be possible to discern if some of the many unknown components in the composite urban waste as well as agriculturally based fertilizers have measurable impacts. The following treatments were established: human urine, sewage sludge (normal N-level and accelerated level aiming at three times normal N-level), degassed and subsequently composted organic municipal waste (normal and accelerated level), deep litter, cattle slurry, cattle manure (accelerated level), NPK fertilizer, unfertilized but with clover undersown and an unfertilized control. After 4 years the soil organic matter (SOM) C content, basal CO_2 respiration and soil microbial biomass (SMB) C was significantly affected by treatments. All soils having received organic fertilizer had higher SMB C than those with no added fertilizer (unfertilized and unfertilized with clover undersown) and inorganic fertilizer. The treatment effect on qCO2 (CO_2/SMB C) was not significant, but the unfertilized treatments showed the highest values. Treatments with accelerated levels of composted household waste and sewage sludge had the highest number of colony forming heterotrophic bacteria. Sole carbon source utilization in EcoPlates indicated a very robust microbial community in the treatments. Cumulative input of heavy metals was less than that required for reaching the heavy metal ecotoxicological limits, even after accelerated loading with sewage sludge corresponding to approximately 55 years of normal application. This could indicate that it is possible use organic urban waste for an extended period on a given site, without compromising soil functioning as long as ecotoxicological guidelines for heavy metal content are observed.

1. Introduction

It is well established that certain key functions of soil biology can be profoundly disturbed by the use of heavy metal polluted sewage sludge, resulting from chronic toxicity effects of Zn, Cu and Cd, especially at moderate or lower pH. Thus both German and British long-term field trials have shown that populations of rhizobia were rendered incapable of fixing atmospheric nitrogen in their symbiosis with white clover due to increased concentrations of Zn, Cu and Cd (e.g. McGrath et al., 1995; Chaudri et al., 1993 and reviewed by Giller et al., 1998). These results were based on application of sewage sludge during the Second World War and post war industrial era. It has been argued that use of heavy metal contaminated waste as fertilizer or soil conditioner should be avoided altogether due to the inevitable accumulation of heavy metals (Witter, 1996). On the other hand, present day urban areas represent a huge sink of nutrients (Faerge et al., 2001) and it may be argued that some of these (notably phosphate (P)) should not be lightly discarded. Recently the realization that P is a limited natural nutrient and thus a disappearing nutrient (Gilbert, 2009), has spurred rising world market prices on phosphorus which is increasingly subject to export restrictions.

In the past decades a significant change in composition of urban organic waste products has occurred in many first world countries, due to cleaner technologies as well as outsourcing of heavy

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doi:10.1016/j.soilbio.2012.02.031

industries. Thus, the heavy metal content of dry matter in sludge from Denmark (Zn, Pb, Cd, Hg) has decreased by a factor 3–5 since 1972 (Anon, 2006). Reviews of organic contaminants in sewage sludge indicate that agricultural recycling is not constrained by concentrations found in contemporary sludge (Clarke and Smith, 2011; Eriksen et al., 2009; Smith, 2009). A recent European Community regulation on Chemicals (EPCEU, 2006) will limit the use of environmentally undesirable chemicals in Europe in the future, and therefore the quality of the urban waste products may be expected to improve further.

It has been shown that it is technically possible to design integrated ecological waste management systems (Magid et al., 2006) based on known components that may be operated at or close to the cost level of the current conventional sanitation systems. Instead of merely delivering composites of urban waste containing numerous undesirable compounds (e.g. heavy metals and xenobiotics in sewage sludge), systems may be developed that can deliver source separated fertilizer of high quality (e.g. human urine, and degassed or composted organic waste including fecal materials or latrine) and limiting the need for purification treatment of sewage water. A number of initiatives on local scale are taken to implement such solutions (Langergraber and Muellegger, 2005; Mnkeni et al., 2008; Jimenez et al., 2006). However, in the foreseeable future the main urban waste sources will remain to be of mixed origin and lesser quality, and thus contain unwanted substances, and lack the most soluble nutrients.

It has been widely-recognised that confusion arises when the toxicity of metals is compared between results from short-term laboratory studies and those from long-term exposures that are often obtained through monitoring of field experiments (Giller et al., 1998, 2009; Renella et al., 2002). Similar issues may well be relevant for other potentially toxic substances that have so far not been identified. In principle any number of substances may be found in urban and agricultural waste products that may be toxic in high enough concentrations. To investigate if the waste in itself is a potential risk for the environment or the integrity of the production system, it was decided to establish a long-term urban waste fertilization trial in 2002.

The key rationale for establishment of the field trial was that by approaching the known limits in a 'realistic' way for a number of heavy metals below which no profound disturbance should be observed on key soil ecological functions, it should be possible to discern if some of the unknown components in the composite urban waste based fertilizers have measurable impacts on these functions. Furthermore an established 'historic' site would be helpful in examining other types of risks (environment and health) that may be considered relevant in the future. The working hypothesis of the long-term experiment is that use of urban waste as fertilizers is not detrimental to soil function in the long-term and beneficial in the short-to-medium term, as long as ecotoxicological limits for heavy metals are not exceeded.

This paper examines the first results on some soil biological functions of normal and accelerated rates of contemporary urban as well as agricultural waste for fertilization. In another paper we examine changes in the microbial community in the same soils using pyrosequencing (Poulsen et al., 2012).

2. Material and methods

2.1. The field trial and its design

The CRUCIAL field trial is a part of a project with focus on closing the rural–urban nutrient cycle and is situated at the experimental farm of the University of Copenhagen, 20 km west of Copenhagen, Denmark (55° 40′ N, 12° 18′ E) on a sandy loam (Magid et al., 2006). Briefly, it includes 11 treatments on 33 plots of 891 m^2 each, in a random block structure. Each plot is separated from the neighbouring plots by a 3 m wide strip of grass, in order to avoid movement of soil between treatments. The site was established in 2002 and based on initial soil analysis it was decided to reduce the plot size resulting in a relatively uniform experimental field with respect to organic-C and texture (Magid et al., 2006). Thus, the field trial has run in its present form since 2003, with the following treatments: human urine, sewage sludge (normal and accelerated level), composted organic municipal waste (normal and accelerated level), deep litter, cattle slurry, cattle manure (accelerated level), NPK fertilizer, unfertilized but with clover undersown and an unfertilized control. All treatments had clover undersown in order to emulate grain production in an organic farming system, except the unfertilized control that was included in order to establish an extreme case of soil quality degradation. The sewage sludge was from a public treatment plant receiving mixed wastewater from industries (not hazardous) and private households. The compost was produced by a private company receiving source separated organic waste from households. The compost had been degassed and subsequently composted and stabilized before use. The deep litter consisted mainly of straw while the cattle manure only had little straw. The fertilizers were spread on land and incorporated by ploughing to approximately 20 cm. The waste/fertilizer input strategy was developed in order to supply a modest input of nitrogen (equivalent to approximately 100 kg N ha^{-1} $year^{-1}$ depending on the crop grown) using single sources and thus annual application rates were adjusted to take mineral fertilizer equivalents (MFE) into account. MFE is an empirical measure of the nutritional effect from organic manuring in comparison to mineral fertilizer that is used in Danish agriculture and based on Danish legislation (Anon, 2011) for regulation of maximum permissible fertilization use. Furthermore in order to allow a possibility of a rapid build-up of heavy metals and other potentially detrimental substances in the soil system we introduced accelerated treatments aiming at three times the normal N-level. These accelerated treatments were expected to approach ecotoxicological limits for Zn and Cu within 8–10 years, rather than 25–40 years of input (Magid et al., 2006). The fields were amended in springtime and grown with spring cereals, and each year the yield and C and N content of the crops were determined. For future reference, an archive was established with samples of the organic fertilizers used every year as well as grain and straw harvested.

2.2. Soil sampling

The soil used in the present study, was sampled in January 2007 (after 4 years of fertilizer amendment). The time of sampling ensured that there were minimal effects of the most recent fertilization episode (April 2006), and that possible effects observed would be representative of the 4 year amendment history. From each of the 33 plots, soil was collected with an auger from the top 20 cm by taking 15 sub-samples in a 3 × 5 grid and pooled. The soil was spread on a table overnight to dry at room temperature and subsequently sieved through a 5 mm sieve and stored at −20 °C. Soil was sampled again in the autumn of 2008 (after 6 years of fertilizer amendment) for determination of soil texture.

2.3. Determination of pH, soil texture, total carbon and nitrogen content

Soil and fertilizer samples were dried at 60 °C overnight for determination of dry weight. Ten g of oven-dried soil was suspended in 25 ml 0.01 M $CaCl_2$ and stirred 5 times within the next hour. The suspension was allowed to settle for 10 min before pH