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Changes in the ecological properties of organic wastes during their biological treatment

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ABSTRACT

Organic wastes, such as the organic fractions of municipal solid waste (OFMSW) or sewage sludge (SS), have become a serious environmental problem in Russia as well as in other countries. The use of these wastes as soil amendments allows their negative impact on the environment to be minimized. However, before these wastes can be used, they need to be treated appropriately in order to decrease their level of hazard. In this study, composting of raw SS, OFMSW, a mixture of these two wastes (OFMSW + SS) at a ratio 1:2 as well as the anaerobically digested variants of these wastes (SSd, OFMSWd and OFMSWd + SSd) mixed with oiled sawdust was performed. Composting was conducted in the containers containing 20 kg of the wastes. The results of three elutriate bioassays (with water flea *Daphnia magna*, infusoria *Paramecium caudatum* and radish plant, *Raphanus sativus*) and one contact bioassay (with oat plant *Avena sativa*) were used to indirectly estimate changes in the hazardous properties of the biological treatments. Besides, C_{org}, N_{tot} content and pH were analyzed in the process of composting. Within the study stability tests to determine maturation process completion were not carried out.

It was revealed, that in the process of anaerobic pretreatment for 15 days, the toxicity increased by a mean of 1.3-, 1.9- and 1.1-fold for OFMSW, SS and OFMSW + SS, respectively. During composting, the toxicity level of these pretreated samples decreased more rapidly as compared with those which were not pretreated. As a result, the toxicity levels of the elutriates from the final composts made of pretreated wastes OFMSW, SS and OFMSW + SS were three-, two- and 17-fold lower for *D. magna* and 15-, 21- and 12-fold lower for *P. caudatum*. As follows from phytotoxicity estimations, composts from digested substrates became mature on the 60th day and had a stimulation effect on the plants after the 90th day of incubation. For the composts prepared from raw substrates, a significantly longer period was needed for maturation. On the basis of ecotoxicity changes of the wastes treated, it can be concluded that anaerobic pretreatment of the municipal solid wastes is an effective acceleration tool for further composting and that waste mixtures can be treated more efficient as compared with raw wastes.

1. Introduction

According to a report by the Ministry of Natural Resources and Environment of the Russian Federation, 5,000,000 tonnes of waste is produced annually across the country (State report..., 2013). Organic wastes, such as the organic fractions of municipal solid waste (OFMSW) or sewage sludge (SS), have become a serious environmental problem in Russia as well as in other countries (Borowski, 2015; Ağdağ and Sponza, 2007; Kapanen and Itävaara, 2001). The management of OFMSW is an important and challenging task in industrialized countries. In Russia, these wastes are mainly disposed of in landfills, which leads to loss of land, underground water pollution by landfill filtrates and the emission of landfill gases, which contribute to the greenhouse effect (Li et al., 2013; He et al., 2011).

In addition, organic wastes after the treatment can be used as soil amendment that can improve soil quality and decrease the use of inorganic fertilizers (Hachicha et al., 2012; Himanen and Hänninen, 2011; Tiquia and Tam, 1998). Since organic wastes are a potential source of organic matter and nutrient elements such as nitrogen, phosphorous and potassium, they can be used for soil fertilization and to increase crop yields.

However, as far as the organic wastes can contain pathogens, heavy metals and other toxic compounds they should be treated

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before they can be used as a soil amendment. Composting is the most common method used to treat organic wastes and can significantly decrease environmental problems caused by the accumulation of wastes (Li et al., 2013; He et al., 2011). This is because during composting, wastes are transformed into safer and stable products that can be used as organic fertilizers (Li et al., 2013; Tiquia and Tam, 1998).

The process of composting is time-consuming, as organic wastes contain heavy biodegradable compounds. To accelerate the composting process and to obtain mature composts more rapidly, preliminary anaerobic digestion can be used. This coupling of the processes is in line with European legislation requirements, which consider the solid fraction of the digestate as a waste product and do not permit its use without preliminary treatment (Directive 2008/98/EC, 2008).

During the process of digestion, non-soluble high-molecular compounds such as lipids, polysaccharides, proteins and nucleic acids are broken down to soluble organic compounds such as amino acids, sugars or fatty acids (Wang et al., 2012; Wong et al., 1983). Many examples of the anaerobic digestion of OFMSW or SS are present in the literature, whereas their co-digestion is more effective (Borowski, 2015; Galitskaya et al., 2014b; Ağdağ and Sponza, 2007). This is primarily because mixing the two wastes leads to an improvement in the balance of the nutrient elements and to an optimum C/N ratio (Borowski, 2015). Furthermore, the mixing of wastes with complimentary properties is reported to be effective for composting (Khan et al., 2014; Zhang et al., 2014; Hachicha et al., 2012).

To characterize the initial wastes and the products of their treatment, chemical analysis (mainly total metals content and their soluble part) and analysis of pathogens is usually carried out. The data obtained, however, are not sufficient to estimate the hazard levels. At the same time, parameters listed in the Hazardous Waste Council Directive (HWD) 91/689/EEC (Direction 91/689/EEC, 1991) allow an assessment of whether the wastes are hazardous. For this purpose, a toxicity-based approach is usually recognized to be the best method for assessing potential hazard. The main advantage of performing bioassays is their integrative character: they integrate the effects of all contaminants that are not considered or detected by chemical analysis, including additive, synergistic and antagonistic effects (Selivanovskaya et al., 2010). A battery of bioassays is usually used to estimate ecotoxicity, which includes an analysis of the elutriate, as well as direct tests using organisms of different taxonomic and trophic levels (Selivanovskaya and Galitskaya, 2011; Pablos et al., 2009). In addition to ecotoxicity estimates, bioassays based on plants are used to estimate compost maturity (El Fels et al., 2014).

In recent years, many attempts to determine the ecotoxicity of various organic wastes have been performed, from sewage sludge to ashes, including different composted materials and/or animal feces (Selivanovskaya et al., 2010; Pablos et al., 2009; Pandard et al., 2006;). Also eco-toxicological investigations are recommended for decision making, concerning the disposal of waste on the land surface. For eco-toxicological analysis, different methods (contacts and elutriates) that use terrestrial and aquatic organisms of different trophic levels are recommended (Domene et al., 2008; Galitskaya et al., 2014a; Huguier et al., 2015; Selivanovskaya et al., 2010; Selivanovskaya and Galitskaya, 2011). However, information concerning changes in the toxicity of wastes during the process of their biological treatment remain insufficient.

In this study, changes in the hazardous properties (estimated on the basis of ecotoxicity) during composting in a lab-scale model experiment using OFMSW, SS and their mixtures, as well as their digested variants, are demonstrated. The results obtained allow improvements in knowledge concerning the anaerobic and aerobic decomposition of organic matter in wastes and recommendations for the most effective method of treatment.

2. Materials and methods

2.1. Collection of raw materials and experiment design

The SS was collected from the wastewater treatment plant of Kazan city (Tatarstan Republic, Russia) and the OFMSW was collected from the waste sorting station of Kazan city (Tatarstan Republic, Russia).

The SS and OFMSW were mixed in a 2:1 w/w ratio. Each of the waste types individually and their mixtures were divided into two parts. The first part was anaerobically digested by the addition of 10% inoculate (a fermentative mass after a previous digestion). Anaerobic digestion for each sample was performed in 3 hermetically sealed 12 L vessels at 55.5 °C and fermentation was performed for 15 days. After 15 days of fermentation, the digestate was dehydrated to a moisture content of 80% and was mixed with oiled sawdust (OS) in a 5:2 w/w ratio, and was further composted in a mesophilic regime for 90 days. The size of the composting piles was 0.03 m^3. The second parts of the wastes fractions and their mixtures were also mixed with OS and composted. Digestion process for each variant was carried out in triplicate. Composting process was carried out in one pile for each variant. During the anaerobic digestion the samples were taken at the beginning and at the end of the process. The wastes and digestates were collected from 5 sampling points and then mixed. During the composting the samples (from 5 sampling points) were taken at the beginning and after 30, 60 and 90 days of the composting.

2.2. Physico-chemical analyses

The C_{org} content was determined by wet oxidation with potassium dichromate (ISO 14235, 1998) and the N_{tot} was determined by the Kjeldahl method (ISO 11261, 1995). The C/N ratio was then computed based on the concentration of C_{org} and N_{tot}. The total content of organic carbon (C_{org}), total nitrogen (N_{tot}) as well as pH was estimated in air dried samples. The pH was measured potentiometrically in water (1:1) (ISO 10390, 2005). Dry matter (DM) was determined after the weight loss by drying wet samples at 105 °C (ISO 11465, 1993).

2.3. Toxicity tests

Toxicity was determined by tests using the protozoan *P. caudatum* (Hussain et al., 2008; Selivanovskaya and Latypova, 2003), the water flea *D. magna* (ISO 6341, 2012) and the higher plants *R. sativus* and *A. sativa* (ISO 22030, 2005).

For ecotoxicological analysis with *P. caudatum*, *D. magna* and *R. sativus* water elutriate was performed from the waste samples. Toxicity to water flea *Daphnia magna*, infusoria *Paramecium caudatum* and higher plants *Raphanus sativus* and *Avena sativa* was estimated in fresh samples immediately after sampling. Extraction was performed by adding 90 mL of water to 9 g of waste, and shaking for 24 h at room temperature. After 15 min of sedimentation, liquid was decanted and the elutriate was centrifuged for 30 min at 3500*g*, decanted again, and filtered. From the solid-phase aqueous elutriate, a dilution range was prepared to provide eight test dilutions (1, 1:1, 1:2, 1:5, 1:10, 1:20, 1:50, 1:100, 1:150 eluate: water). For negative control the water was used.

The tests with *D. magna* were performed in 50-ml beakers, filled with 20 mL of the test dilution. Five test organisms (aged 6–24 h) were subsequently added to each solution and were not fed during

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