

Article

Ecotoxicity of In-Situ Produced Compost Intended for Landfill Restoration

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Abstract: Municipal solid waste (MSW) has become a matter of increasing global concern. Biological conversion is considered to be the most applicable disposal method, especially for the organic fraction of MSW. The aim of this study was to evaluate composting as a treatment method for the sustainable management and recycling of MSW and to test the ecotoxicity of the compost produced on the landfill surface. The ecotoxicity of the compost was investigated by means of a set of biological tests. The ecotoxicological impact of the compost was evaluated by plant growth tests with white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.). Plants were grown under controlled conditions for 21 days, in earthen pots, treated with MSW compost (MSWC) to study the effect of MSWC on plant biomass production. Sprouts and the number of growing plants occurring in the earthen pots were counted. The values obtained from three simultaneously conducted experiments were averaged and presented. Plants growing in the earthen pots with the compost exhibited increasing plant biomass while no changes were observed in their appearance; retarded growth or necrotic changes were not recorded. The ecotoxicity tests performed show that the analyzed compost produced in the composting plant situated on the landfill surface achieved high percentages of the germinating capacity of white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) seeds and can be therefore used in the subsequent reclamation of the landfill concerned.

Keywords: landfill; compost; ecotoxicity tests; *Sinapis alba* L.; *Hordeum vulgare* L.

1. Introduction

An estimated $1.3\text{--}1.9 \times 10^{15}$ kg of municipal solid waste (MSW) is produced every year worldwide. This amount is expected to grow roughly to 2.2×10^{15} kg MSW per year by 2025 and thus it is becoming the subject of global concern [1,2]. The best method for eliminating organic fractions, particularly in case of MSW, is biological conversion [3,4]. MSW comprises a considerable degree of organic waste that can be efficiently and inexpensively used for composting. This method may increase the content of organic components in soil and protect the environment [4]. Economically, composting is a superior way of treating waste to incineration [4,5].

EU Directive 1999/31/EC on the landfill of waste sets objectives for reducing the amount of biodegradable MSW deposited in a landfill. By 2010, the amount should be reduced to 75% compared to 1999 and to 35% by 2020 [6]. By removing organic compounds from waste deposited in a landfill the landfill gases, for instance CH₄ or CO₂ [7] will subsequently drop. Compared to landfilling the biodegradable fraction of MSW, the alternative of high technology composting, including the separation of waste, is a much more economic and efficient way of treating waste.

Biological treatment such as composting of the organic fraction of MSW (OFMSW) is an environmentally and economically viable solution [8]. Composting of OFMSW is seen as a method of diverting organic waste materials from landfills while creating a product, at low-cost, that is suitable for reclamation purposes [9]. Composting on the landfill surface brings many benefits. A closed landfill cell is a very suitable and safe space for composting. In addition, it has a positive effect on the limitation of transport, emission and noise. The waste is managed in one place. This strategy (composting plants located on the closed landfill cell) is not very obvious or widely used. In a typical landfill, much of the waste containing 60% or more in organic content is buried [10]. However, at the Kuchyňky landfill the OFMSW is transformed to compost and used at the same place.

Working compost into the soil [11] is the most common way of raising soil productivity and replacing organic matter (OM) losses in agriculture. Greenhouse gas emissions may be diminished by adding compost as a soil conditioner or fertilizer. Biogenic carbon in soils is sequestered. Compost application improves the physical characteristics of soil, thus returning the basic nutrients back to the soil. Directives regulating the quality of compost have been established in a number of countries [7].

Due to a lack of commonly used materials for compost making, MSW compost (MSWC) is used to make compost for agricultural purposes. The demand for MSWC keeps growing and its application is becoming more and more popular [12].

However, working MSWC into the soil may involve certain health and environmental risks that are often neglected. Solid waste may be contaminated with chemically and biologically harmful substances that embody health risks for people [13]. The quality of compost may have both positive and negative impacts on plant viability. Many physicochemical parameters (temperature, pH, proportion of carbon and nitrogen or the contents of nutrients) may be organic compost stabilization indicators [14]. However, these parameters do not deliver sufficient information on the residues in MSW or indicate whether their application for agricultural purposes is environmentally safe [14,15]. Using the additional method of assessing ecotoxicity is advantageous in determining compost stabilization [14,16,17]. The ecotoxicity test monitors the germination of seeds of various species of plant as indicators of biological responses to the stabilization of biosolids [14]. Therefore, the objective of this study is to assess composting as one of the methods of sustainable MSW and its recycling and to carry out ecotoxicity tests on compost samples produced on the surface of the landfill. The ecotoxicological impact of the compost was tested using ecotoxicity tests with white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.).

2. Materials and Methods

2.1. Site Description

For this research the Kuchyňky active landfill site located near the medium-sized city of Zdounky (population of 75,000) in the Czech Republic (CR) was used (Figure 1). The landfill (49°14.458 N, 17°18.527 E) is located 1.5 km from the town center. The landfill is classified in the S-category—other waste, S-OO3 subgroup with separate landfill subgroups of S-OO1 under Ministry of the Environment Decree No. 294/2005 Coll., on the conditions of depositing waste in landfills and its use on the surface of the ground and amending Decree No. 383/2001 Coll., on details of waste management. The landfill has a degazation system and protective fence. The site is fenced off, covering 18.4 ha site. The landfill area covers 70,700 m² in five stages with a total volume of 907,000 m³, i.e. ca. 1,000,000 × 10³ kg of waste. The body of the landfill in the stage I. takes up 1.9 ha, in stage II.a. 0.55 ha, stage II.b. 0.45 ha

and 0.75 ha in stage III.a. It has been in operation since 1995. Detailed site operational activities of the landfill sites are reported in Adamcová 2016 [12].

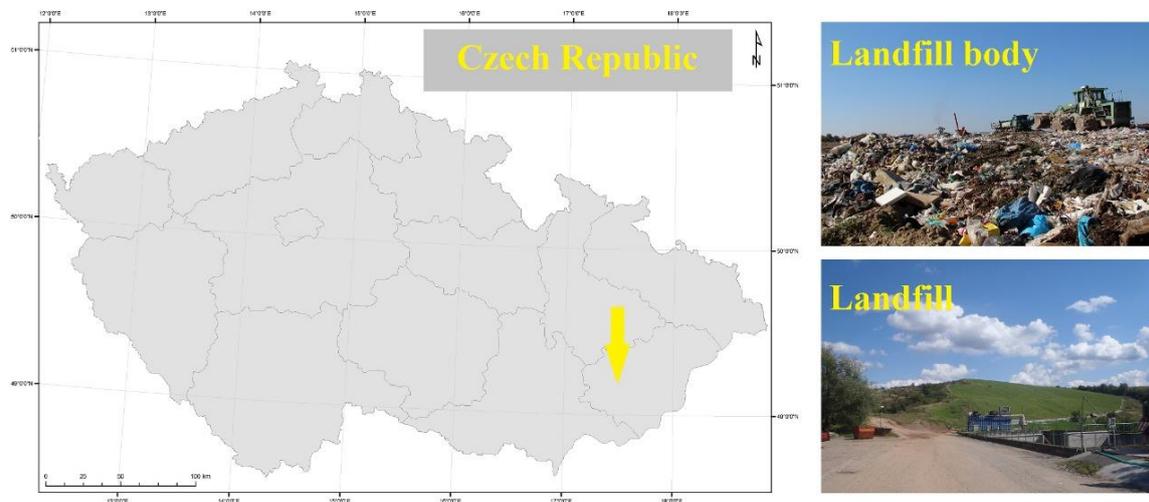


Figure 1. Scheme and aerial photograph (insert) of the landfill site.

2.2. Composting at the Landfill Body

The composting plant is located on the surface of the Kuchyňky landfill (Figure 2). Biologically degradable waste (BDW) brought from surrounding villages and towns is composted here. This involves the green stuff from the maintenance of municipal greenery, as well as biologically degradable municipal waste (BDCW) obtained from local people in the collection area.

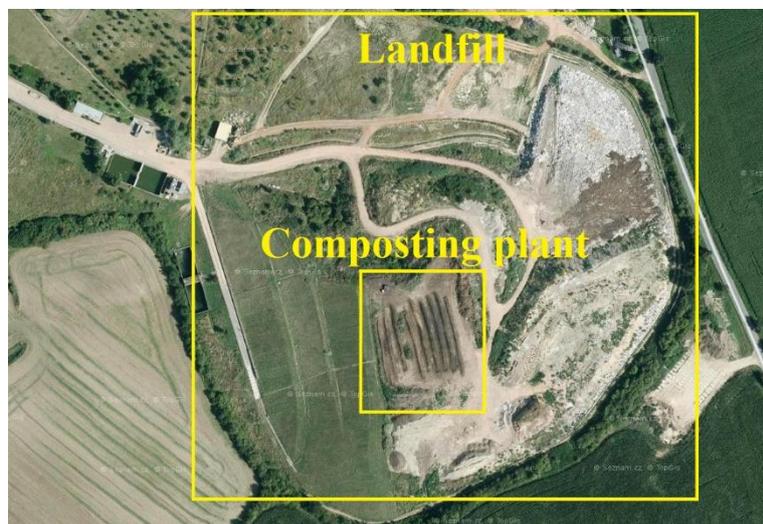


Figure 2. Location of composting plant.

The projected capacity for waste accepted into this composting plant is 2000×10^3 kg/year. This site will collect, purchase and use waste—waste management under the R3 code pursuant to attachment No. 3 of the Waste Management Act as later amended. The composting area is located in a site where waste depositing has already come to an end. The place had been restored, covered with recycled material and soil and compacted. The acreage of the composting site is 20×30 m. It consists of 6–8 composting piles with a 30×1.5 m triangular profile 0.8 m high (Figure 3). The produced compost is used as a reclamation material for the Kuchyňky landfill [12]. Aerobic conditions were

accomplished by mechanical turning. The turning was accomplished with specialized equipment. Composting piles were turned upside down every 7 days.



Figure 3. Composting piles located on the landfill surface and ready compost.

2.3. Composting Materials

The OFMSW includes food waste, leaf and yard waste. A significant proportion of organic material represents a food waste from restaurants and hospitals or comes from distribution and retail agents. Leaf and yard waste consists of lignocellulose-based materials, such as green grass clippings and thatch, leaves, weeds, brush, and tree prunings, whose production varies widely through the year. A further, although minor, contribution to the lignocellulose content of organic MSW is provided by soiled paper. The basic physico-chemical characteristics of the compost are presented in Table 1.

Table 1. Physico-chemical characteristics of the compost.

Parameters	Results	Unit
DM	41.56	%
pH	6.5	
C/N	32	
Conductivity	169	$\mu\text{S}/\text{cm}$
Organic carbon	35	% DM
Total nitrogen	1.21	% DM
Phosphorus	2.65	g/kg DM
Potassium	11.9	g/kg DM
Zinc	178	mg/kg DM
Cadmium	0.58	mg/kg DM

DM: dry matter.

2.4. Sampling Strategy

Compost samples were collected from April through September 2017. The frequency of collecting the samples was once a month. Samples (2 kg/sample) were collected in sterile collection containers. The samples were stored in airtight polyethylene containers and transported to the laboratory for analysis. Changes and toxic effect of composts were determined using *Sinapis alba* L. and *Hordeum vulgare* L. The samples were always collected at the end of the composting process from the selected pile. Remaining samples were kept (for further analysis) in a freezer at $-18\text{ }^{\circ}\text{C}$ in the dark in order to keep its characteristics constant.

2.5. Ecotoxicity Test

The experiment was carried out in laboratory conditions. The effect of compost ecotoxicity on the plant biomass was determined with: white mustard (*Sinapis alba* L.—SIA) and barley (*Hordeum vulgare* L.—HOV) bioassays. Plant seeds were the indicators for the ecotoxicity test, following procedures adapted from those described in CSN EN 13432 *Packaging—Requirements for packaging recoverable through*

composting and biodegradation—Test scheme and evaluation criteria for the final acceptance of packaging. The medium was commercial potting soil for germination and plant growth and silica sand (8:2), enriched with compost (25%, 50% *w/w*). A soil sample (85% air-dried quartz sand, 10% kaolin clay, 5% sphagnum peat, calcium carbonate) without compost amendment was used as a control. After air-drying the medium was sieved with a 2 mm standard sieve and stored until analyses were provided. Experimental earthen pots were filled with 200 g of medium, then 100 seeds were scattered onto the surface, covered with a thin layer of silica sand and the pots were covered with a glass plate (to avoid evaporation). Seeds used for the pot experiment were commercially available seeds. When the germinated and growing plants touched the glass plates they were removed. Plants were grown under general laboratory conditions for 21 days. Humidity (at a level of 70% of water absorption capacity), the low light intensity and the laboratory temperature (22 ± 2 °C), were kept constant. There were three replicates per treatment. The results obtained were averaged. During the experiment the missing water (evaporated water) was refilled as needed.

2.6. Determination of Biomass

Biomass samples (Wet—W, Dry—D: SIA 25% W, SIA 50% W, HOV 25% W, HOV 50% W and SIA 25% D, SIA 50% D, HOV 25% D, HOV 50% D) were collected and weighed on Precisa 4000 C scales. The biomass was inserted into paper bags and dried in an ECOCELL dryer (at 45 ± 2 °C). After drying, the biomass was weighed on Precisa 4000 C scales. The results are shown in Table 2 and Figure 5.

The results were subjected to statistical analysis calculating mean values and standard deviations. Significant differences between objects were determined using two-factor analysis of variance (ANOVA) and Duncan's test at the significance level of $p < 0.05$, using the Statistica software package (StatSoft Polska, Crakow, Poland) [18].

3. Results

The compost produced in the given composting plant was sampled. The samples were designated as A (April), B (May), C (June), D (July), E (August) and F (September). After 14 and 21 days, the number of growing plants and plant biomass were assessed for A–F samples. The number of growing plants and plant biomass was evaluated (Figure 4).



Figure 4. Illustration of the plant biomass of *Sinapis alba* L. and *Hordeum vulgare* L.

Figure 5 presents percentages of the number of growing plants of white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) seeds (25%, 50% of samples A–F) after 21 days from the beginning of the experiment.

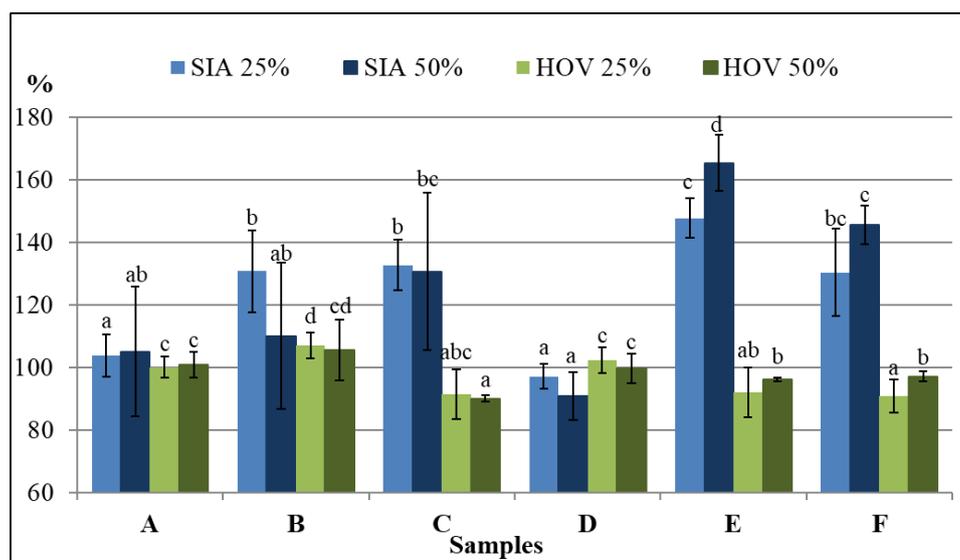


Figure 5. Comparison of the percentages of the growing plants in (A–F) compost samples. Mean values \pm standard deviation ($n = 3$). Different letters indicate significant differences between number of growing plants for the same plant, $p < 0.05$.

The germinating capacity of seeds and plant growth were 97–148% for SIA 25% A–F samples and 91–165% for SIA 50% A–F samples. The average germinating capacity was 124% for SIA 25% A–F samples and 125% for SIA 50% A–F samples. The germinating capacity of seeds and plant growth were 91–107% for HOV 25% A–F samples and 90–105% for HOV 50% A–F samples. The average germinating capacity was 97% for HOV 25% A–F samples and 98% for HOV 50% A–F samples. The highest germinating capacity of seed was achieved in samples SIA 50% A–F. Pursuant to the standard, values below 90% are considered slightly toxic. Only sample HOV 50% C was toxic. Samples HOV 25% A–F and HOV 50% A–F have a lower germinating capacity than samples SIA 25% and SIA 50%, on average by 27%.

The weight biomass of white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) are shown in Table 2.

Table 2. Weight biomass of white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.).

<i>Sinapis alba</i> L.	25%		50%	
	(g)	W	W	D
A	1.21b	0.3c	1.25bc	0.29c
B	0.96a	0.34d	1.01a	0.28c
C	1.11b	0.33d	1.17b	0.36
D	1.61d	0.34d	1.22b	0.15a
E	1.31bc	0.25b	1.21b	0.24b
F	1.46c	0.25b	1.58d	0.35d
<i>Hordeum vulgare</i> L.	25%		50%	
A	14.75d	1.13c	14.44c	1.16d
B	13.48b	1.11b	15.6d	1.18d
C	12.65a	1.04a	11.42a	0.9a
D	14.6cd	1.12bc	16.47e	1.34e
E	14.47c	1.14c	18.5f	1.50f
F	13.01b	0.98a	15.23d	1.35e

Mean values ($n = 3$). Different letters indicate significant differences between weight biomass for the same plant and kind of weight, $p < 0.05$.

In the period under scrutiny, the weight of wet biomass for the test plant *Sinapis alba* L. with 25% proportion, oscillated between 0.96 and 1.61 g. The average weight of wet biomass for all tested

samples was 1.28 g. In the case of 50% proportion of the tested compost, the weight of the wet biomass oscillated between 1.0 and 1.58 g, and the average value was 1.24 g. The choice of the proportion of tested compost samples in the case of *Sinapis alba* L. therefore did not affect the wet biomass weight. Individual compost samples (A–F) manifested similar results of wet biomass weight in the case of both tested proportions of 25% and 50%, while no sample of the tested composts showed any distinctive deviation in the wet biomass weight. Comparable results were ascertained also in the case of dry biomass weight for the tested *Sinapis alba* L. In the period under scrutiny, the weight of the dry biomass in the case of 25% proportion oscillated between 0.25 and 0.34 g, and the average weight of dry biomass in all tested samples was 0.30 g. In the case of 50% proportion the weight of the dry biomass oscillated between 0.15 and 0.36 g, and the average value was 0.28 g.

In the period under scrutiny, the weight of the wet biomass for the tested plants of *Hordeum vulgare* L. with 25% proportion oscillated between 12.65 and 14.75 g, and the average weight of wet biomass from all the tested samples was 13.83 g. In the case of a 50% proportion of the tested compost the weight of the wet biomass oscillated between 11.42 and 18.50 g, and the average value was 15.28 g. The choice of the proportion of tested compost samples in case of the *Hordeum vulgare* L. plant therefore did not influence the weight of the wet biomass. Individual compost samples (A–F) manifested similar results of wet biomass weights in the case of both tested proportions of 25% and 50%, while no sample of the tested composts showed any distinctive deviation in the wet biomass weight. Comparable results were ascertained also in the case of dry biomass for the tested *Hordeum vulgare* L. plant. Within the period under scrutiny the weights of dry biomass with a 25% proportion oscillated between 0.98 and 1.14 g, and the average value of dry biomass for all tested samples was 1.09 g. In the case of the 50% proportion of tested compost samples, the weight of the dry biomass oscillated between 0.90 and 1.35 g, and the average value was 1.24 g.

The samples A–F *Sinapis alba* L. have a higher weight of dry and wet biomass under the 25% compost proportion than with the 50% compost proportion. *Hordeum vulgare* L. showed (April–September) a higher weight of dry and wet biomass with the 50% proportion of the tested compost than the 25% one.

4. Discussion

Composting significantly reduces the volume of waste while simultaneously producing valuable soil amendment product [19,20]. Numerous studies have been carried out to define the chemical, physical and microbiological characteristics of the composting process [20–23] and of compost as fertilizer, but such research aimed to analyze the ecotoxicity of compost and possibility of using compost produced on the closed landfill cell are not yet exhaustive. In order to use compost produced in non-standard conditions (MSW landfills create very specific conditions), an ecotoxic analysis of this product is needed. In our study all the composts do not manifest ecotoxicity. This finding provides evidence that compost produced on the landfill surface can bring many environmental benefits e.g., biodegradable waste not being landfill, emissions of greenhouse gases are avoided reduction of transport, emission and noise. The material is used at the place where it has been produced which is in accordance with resource management. Moreover, there is a necessity of the quick reclamation of the full landfill cells [24,25]. After the cells are closed, the impact of waste on the environment will be minimized.

5. Conclusions

Landfilling is the worst waste management option for the organic fraction of municipal solid waste. Composting on the closed landfill cell is a promising method for effective and environmentally friendly use of biodegradable waste. The most significant benefits of proper biodegradable waste management—besides avoiding emissions of greenhouse gases—is the production of good quality compost. Samples from the compost under scrutiny show no ecotoxic effect. It is therefore possible to use the tested compost as a soil amendment or landfill cover material. This is substantiated

by the results of the biomass for both tested plants, white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.).

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