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ENVIRONMENTAL IMPACT OF LANDFILL ON SOILS – THE EXAMPLE OF THE CZECH REPUBLIC

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Abstract. This study focuses on the impact of a municipal solid waste (MSW) landfill on the environment. Phytotoxicity test was determined to assess ecotoxicity of landfill soil (Zdounky-Kuchyňky). White mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) plants were allowed to grow in earthen pots, treated with soil samples to study the potential effect of landfill to the plant biomass production. Twenty-one days from the establishment of the experiment, sprouts and the number of growing plants occurring in the earthen pots were counted. The conducted research shows that the soil from the area of the landfill is not phytotoxic. According to the results of this research, it is possible to claim that the Zdounky-Kuchyňky MSW landfill is not a considerable source of pollution for the environment in present days.

Keywords: waste treatment, landfill, soil, pollutions, growth inhibition test

INTRODUCTION

Integrated solid waste management (SWM) practices, which include source reduction, reuse, recycling, and composting, have decreased the use of landfills (Bhatt *et al*. 2017). However, landfilling still remain the most common form of

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removal and disposal of municipal solid waste (MSW) (Adamcová and Vaverková 2016, Gworek *et al.* 2016, Vaverková *et al.* 2017). Landfills are one of those humans' activities that are changing the fate of natural ecosystems (Gworek *et al.* 2016, Wong *et al*. 2016).

In total, 1.3 billion tons of MSW are produced globally, at an average daily rate of 1.2 kg per capita. By 2025 this amount will increase to 2.3 billion tons per year. Although final disposal of MSW is considered the least desirable option, it remains the predominant solution worldwide. Approximately 80% of global MSW is placed in waste disposal sites, of which only 20% is contained in engineered and controlled landfill sites (Caicedo-Concha *et al.* 2016).

There are many reactions and transformations (chemical, biological and physical) that occur within waste that result in formation of a number of harmful chemicals and substances (Koda *et al.* 2015, Adamcová *et al.* 2017). The MSW landfills are potential sources of groundwater, soil and plant pollution by heavy metals (Gworek *et al.* 2016). Landfill leachate is generated mainly due to the infiltration of rain water which percolates through the waste layers and accumulates at the bottom of landfills. Even though MSW practices for landfilling of wastes have advanced, leachate generation and management remains one of the most important issues associated with landfills (Mahmud *et al.* 2012, Tatsi and Zouboulis 2002, Bhatt *et al.* 2017). This leachate can cause pollution of surrounding soil, surface waters, and ground water. Another impact of landfills is that they result in the sealing or/and degradation of the soils, which are relevant to understand the Earth System functioning as they determine the biological, erosional, hydrological and geochemical Earth cycles and the degradation of the soils will risk the services, goods and resource the soils offer to the humankind (Keesstra *et al.* 2012, Mol and Keesstra 2012). The contamination of the soil environment is a more and more frequently occurring problem throughout the world (Sas *et al*. 2015, Radziemska *et al.* 2013).The observed changes in the chemical composition of soil and plants are the consequence of the contamination of individual components of the natural environment by progressing and degrading anthropogenic activity (Adamcová *et al.* 2016, Sas *et al.*2015, Radziemska and Wyszkowski 2017, Radziemska *et al.* 2017). This is why it is necessary to research how the soils are affected by the use by the human societies (Adamcová *et al.* 2016).

Ecotoxicological methodologies are widely used in order to assess environmental risks of pollutants and complex mixtures (Aziz *et al.* 2004, Morozesk *et al.* 2016). In order to analyze the landfill environmental risks and impact to agricultural land, a quick method to evaluate its phytotoxicity is essential.

A relatively easy and quick method to test phytotoxicity of chemical substances is a bio-assay, using for example a germination test with white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.). This test is often used to evaluate toxicity of organic fertilizers. Phytotoxicity in such a seed germination bio-assay is the capability of substances to inhibit or reduce seed germination or root growth (Břoušková *et al.* 2015, Reijs *et al.* 2003).

The present research was aimed at assessing the soil pollution at the landfill site (in operation) and in the vicinity of a MSW landfill site. The results of a study of the environmental effects of a MSW landfill in the Czech Republic are presented. To account for the impacts of the MSW landfill on the surrounding areas, samples of soil were taken. The main objective was to study the soil toxicity using the white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) growth inhibition test.

MATERIALS AND METHODS

Landfill site description

The Zdounky-Kuchyňky landfill (49.2490778N, 17.3121181E) is classified in the S-category for ‘other waste’, sub-category S-OO3 (Fig. 1). It started operating during 1995. The area of the landfill is 70,700 m^2 in five stages, with a total volume of 907,000 m^3, i.e. around $1{,}000{,}000 \cdot 10^3$ kg of waste. The planned service life of the facility has been prolonged up to 2027. The facility receives waste (in the category of ‘other waste’) from a catchment area with a population of around 75,000 residents. The annually deposited amount of waste is around $40{,}000 \cdot 10^3$ kg, of which 50% is from the communal sphere (Adamcová and Vaverková 2016, Voběrková *et al.* 2017). The landfill contains non-hazardous waste including MSW.

Fig. 1. Scheme and aerial photograph (insert) of the landfill site and sampling points

Soil sampling

Soil samples were collected on the sanitary landfill in 2014 and 2015. To account for the impacts of the landfill on the surrounding areas, samples of soil were taken, at the places marked in Figure 1. Soil samples were collected (in sterilized plastic containers) from 3 places on the landfill body (Sample 1–3) and 1 sample was collected in the nearest surrounding of the landfill (Sample 4). The allocations of sampling sites were chosen on the basis of the authors` decision and on the grounds of mutual comparison of the landfill body and its borders with the nearest vicinity of the landfill (agriculturally utilized soil and forests). Samples were collected with a hoe and a small shovel to obtain an average sample of topsoil (±2 kg) in each zone that was subsequently used for phytotoxicity tests. They were air dried, sieved using a 2 mm mesh, and stored in sampling bags for analysis.

Analysis of soil samples for its chemical parameters

Soil is one of the most important resources that are being contaminated with heavy metals (Radziemska and Wyszkowski 2016). Soil pH (KCl) was measured in 1 mol dm^{-3} potassium chloride solution, according to ISO norm no. 10390:2005 (ISO, 2005) – Soil quality. The organic carbon in soil by sulfochromic oxidation was estimated according to ISO 14235 – Soil quality. A Delta Premium PXRF (Olympus Innov-X, Woburn, MA, USA) was used to scan each of the soil samples *ex-situ*. The Delta Premium PXRF features a Ta/Au x-ray tube operated at ~ 15–40 KeV with quantification via ultra-high resolution (<165 eV) silicon drift detector. The Delta PXRF was calibrated using a stainless steel ‘316’ alloy clip tightly fitted over the 2-cm aperture. Scanning consisted of 30 seconds per beam with the light element analysis program (LEAP) engaged in a proprietary software configuration known as Soil Mode for optimal elemental quantification. Elemental quantification included Si, K, Ca, Ti, Mn, Fe, Zn, As and Pb. The quantity of each element was reported in mg kg^{-1} along with the limit of detection, defined as three times the standard error.

Soil samples were collected from each site for laboratory validation of previously established characterization data. Validation samples were air dried, disaggregated to pass a 2-mm sieve, and subjected to total C total N analysis via Dumas method high temperature combustion using a model 1000 CHN analyser (LECO TruSpec CN –LECO Corp., St. Joseph, MI, USA). All treatments were replicated three times. The means and relative standard deviations (±RSD) were calculated using Microsoft Office Excel 2010.

Plant material

Seeds used as plant material for testing were commercial seeds of white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.). They were selected because they are known to be sensitive to board range of chemicals. White mustard (*Sinapis alba* L.) is ideal for studying soils and soil extracts (Adamcová *et al.* 2016, Gerencsér *et al.* 2010, OECD Guideline 208 for the Testing of Chemicals 2003). Seeds were surface-sterilized by soaking for 2 min in a commercial sodium hypochlorite (2%) solution with a few drops of Tween-20. Then they were rinsed twice in sterile distilled water.

Phytotoxicity test – Pot experiment layout

The experiment was developed in a laboratory conditions. Phytotoxicity of soil samples was investigated by means of a set of biological tests. Two crops were selected according to their different toxicity tolerance: white mustard (*Sinapis alba* L. – SIA) and barley (*Hordeum vulgare* L. – HOV) (Fig. 2). Selected seeds were the bioindicators for the phytotoxicity test, following procedures adapted from those described in CSN EN 13432. Reference soil was composed of commercial potting soil and silica sand (8:2) and manually homogenized to reach equilibrium conditions. The medium was commercial potting soil for germination and plant growth and silica sand (8:2), enriched with soil samples from landfill and landfill surrounding (25%, 50%). The medium was sieved with a 2-mm standard sieve after air-drying and was stored in a dryer.

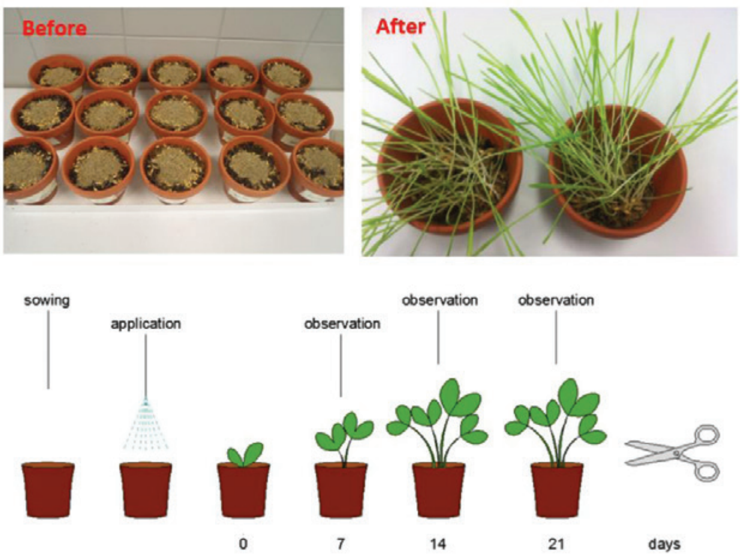

Fig. 2. Experiment principles – set of biological tests

Each earthen pot with a diameter of 11 cm and a height of 10 cm was loosely filled with 200 g of medium, then 100 seeds were scattered on to the surface, covered with a thin layer of silica sand and the earthen pots were covered with a glass plate (to avoid evaporation). Glass plates were removed when the germinated plants touched them. Plants were grown under controlled conditions for 21 days. Humidity at the level of 70–100 % of water absorption capacity, low light intensity, and the laboratory temperature were maintained to be constant. The experimental design was based on the use of three replicates per treatment. Values obtained from three simultaneously conducted experiments were averaged and presented (germination capacity). During the experiment, evaporated water was regularly added as needed (Břoušková *et al.* 2015).

RESULTS AND DISCUSSION

Chemical composition of soil

The rehabilitation of contaminated sites requires a detailed knowledge on the chemical contaminants and the pathways by which the contaminants can reach environmental and human targets (Critto *et al*. 2003, Mazur *et al.* 2013). Landfills may pose serious threat to groundwater resources and soil. Many studies show evidence of seriousness of hazards caused by landfills (Ahmed and Sulaiman 2001, Critto *et al.* 2003, Gworek *et al.* 2016, Koda *et al.* 2016). However, the main source of contamination of the environment with heavy metals is the transportation infrastructure, which includes roads, bridges and overpasses.

The results obtained for chemical properties of soils at both control and waste disposal sites are shown in Table 1 and 2. The physical, chemical, and biological properties of soil are directly dependent on its pH value (Chatzistathis *et al.* 2015). Soil samples collected at sampling locations nearest to the road in the present study were characterized by a pH_{KCl} an average value of 6.58. Studies conducted by Lee *et al*. (2012) confirmed a higher pH of soil in the direct proximity of a road. Numerous factors may have led to the differences in the values of pH determined in the soil samples collected from the analyzed stretch of the transport route. International research centers have documented the negative influence of roads on the physicochemical properties of water and soil (MacKay *et al.* 2011, Rijkenberg and Depree 2010, Piguet *et al.* 2008, Radziemska and Fronczyk 2015). The main sources of heavy metal contamination in the proximity of roads are tire and brake abrasion, combustion exhaust, pavement wear and the application of road salt in the winter period. De-icing salts are necessary in winter to maintain traffic flow and keep roadways safe for human travel (Hintz and Relyea 2017), however, 75–90% of the applied de-icing salt enters the roadside environment directly in runoff and as splash or aerosol deposition (Green *et al.* 2008). Salt is also seen as an environmental pollutant, having a negative effect on vegetation.

TABLE 1. CHEMICAL PROPERTIES OF SOILS SAMPLES IN 2014 AND 2015

Sampling points 2014	pH/KCl	N_{tot} %	RSD	C_{tot} %	RSD	C:N
1	5.48	0.137	0.039	1.49	0.051	10.92
2	5.37	0.131	0.045	1.57	0.006	11.93
3	5.95	0.124	0.081	1.43	0.003	11.59
4	6.55	0.136	0.036	1.48	0.004	10.88
Sampling points 2015	pH/KCl	N_{tot} %	RSD	C_{tot} %	RSD	C:N
1	5.58	0.135	0.039	1.49	0.049	11.03
2	5.74	0.130	0.044	1.58	0.006	12.15
3	6.20	0.122	0.079	1.44	0.004	11.80
4	6.61	0.134	0.037	1.51	0.004	11.26

RSD: relative standard deviation

TABLE 2. HEAVY METALS COMPOSITION OF SOILS SAMPLES

Sampling points 2014	Si	Ti	Mn	As
1	7.92±0.16	0.26±0.03	0.051±0.01	<LOD
2	10.7±0.20	0.34±0.03	0.056±0.01	0.007±0.001
3	5.79±0.14	0.59±0.03	0.075±0.01	0.007±0.002
4	6.24±0.15	0.25±0.03	0.043±0.06	0.001±0.001
Sampling points 2014	Fe	Zn	Pb	
1	2.38±0.03	0.021±0.002	0.004±0.001	
2	3.02±0.04	0.010±0.001	0.003±0.001	
3	4.85±0.05	0.270±0.005	0.112±0.003	
4	2.69±0.04	0.010±0.001	0.002±0.001	
Sampling points 2015	Si	Ti	Mn	As
1	8.22±0.16	0.27±0.03	0.052±0.01	<LOD
2	9.75±0.20	0.33±0.03	0.055±0.01	0.002±0.001
3	5.69±0.12	0.58±0.03	0.076±0.01	0.007±0.002
4	6.25±0.13	0.24±0.03	0.042±0.01	0.002±0.001
Sampling points 2015	Fe	Zn	Pb	
1	2.41±0.03	0.02±0.001	0.005±0.001	
2	3.03±0.04	0.01±0.001	0.004±0.001	
3	4.87±0.05	0.31±0.005	0.113±0.003	
4	2.69±0.04	0.01±0.001	0.002±0.001	

LOD: limit of detections, mean±SD, n=3

The contents of the analysed elements in the soil samples depended on the site from which the samples were taken. The average metal concentrations at all sampling sites can be ranked as follows: Fe>Si>Ti>Zn>Mn>Pb>As. From the chemical analysis of soil samples, the values of metals varied over a wide range as follows: 5.69–10.70 mg/kg for Si, 0.24–0.59 mg/kg for Ti, 0.042–0.076 mg/kg for Mn, 0.001–0.007 mg/kg for As, 2.38–4.87 mg/kg for Fe, 0.002–0.113 mg/kg for Pb and 0.04–0.270 mg/kg for Zn. Pb values in soil samples varied between 2.50 and 93 mg/kg in the study by Kasassi *et al.* (2008) in Greece and by Jain *et al.* (2005) in California. This could be attributed to the different type of wastes deposited at this area. The existence of Zn in the soil was associated mainly to the near-by significant traffic emissions from the aforementioned road. By comparing average values of Zn measured in Spain (Schuhmacher *et al.* 2002), Jordan (Al-Khashman and Shawabkeh 2006), and Greece (Kasassi *et al.* 2008) it can be stated that the values measured in the Czech Republic were lower than the Spanish, Greek and Jordanian ones.

Phytotoxicity study

Values were calculated from the obtained data (Table 3) and results were evaluated. The number of sprouts (number of growing plants) occurring on samples of examined soil and on the soil from the blank experiment was compared for all mixing ratios. Germinating capacity was calculated as a percentage of the corresponding values obtained from soils in the blank experiment.

TABLE 3. RESULTS FOR GERMINATION CAPACITY OF SEEDS OF *SINAPIS ALBA* L. AND *HORDEUM VULGARE* L. FOR EXAMINED SAMPLES

Sampling points 2014	SIA 25%	SIA 50%	HOV 25%	HOV 50%
1	66	60	91	88
2	64	62	87	84
3	59	57	77	88
4	58	55	80	76
References	60	60	82	82

Sampling points 2015	SIA 25%	SIA 50%	HOV 25%	HOV 50%
1	73	67	90	88
2	69	64	70	76
3	73	74	79	79
4	84	71	75	67
References	66	66	67	67

The germination stages and pot experiment set up are presented in Figure 2. The germination stage is the first exchange interface with the surrounding medium and accordingly it is relatively sensitive to changing environmental conditions (Bae *et al.* 2016, Shah *et al.* 2010). Moreover, germination – an important stage in the life cycle of plants – is susceptible to the presence of soil contaminants. Figure 3 shows the percentage expression of germination capacity of seeds of *Sinapis alba* L. and *Hordeum vulgare* L. (25% and 50% share of sampling points 1–4 year 2014) after 21 days (end of the experiment).

Figure 4 shows the percentage expression of germination capacity of seeds of *Sinapis alba* L. and *Hordeum vulgare* L. (25% and 50% share of sampling points 1–4 year 2015) after 21 days (end of the experiment).

The present study showed that an increase in plant biomass for both years (2014 and 2015) was observed in plants growing in earthen pots with soil samples taken from the landfill body and landfill vicinity, but no changes in appearance, slow growth or necrotic lesions appeared. Ecotoxicity tests carried out on samples taken in 2014 show that tested soils (at a concentration of 25%) collected from the landfill body, edge of the landfill body and its vicinity reach high percentage values of germination capacity of seeds, and extend from 100% to 111% for white mustard (*Sinapis alba* L.) and for barley (*Hordeum vulgare* L.) ranged from 94% to 107% (Fig. 3). Simultaneously, the tested soils at a concentration of 50% achieve irrelevant lower percentage values of germination capacity of seeds of white mustard (*Sinapis alba* L.) from 102% to 107% and for barley (*Hordeum vulgare* L.) from 92% to 98%, respectively (Fig. 3).

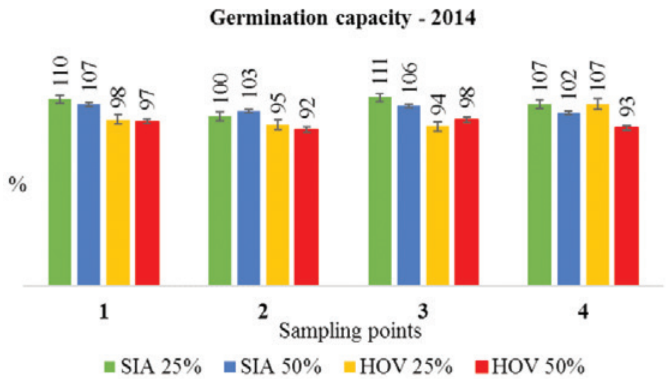

Fig. 3. Germination capacity in 2014

From the data in Figure 4, it is apparent that tested soils (at a concentration of 25% and 50%) reached a bit higher value of germination capacity of seeds (compared to year 2014), the seed germination capacity in all 4 samples of tested soils range between 97% and 131%.

Germination bioassays have been adopted to evaluate the phytotoxic effects of heavy metals (Chang *et al*. 1992) and herbicides (Boutin *et al*. 2004, Kaur *et. al.* 2017). Soil phytotoxicity consistently affects germination dynamics (Sharonova and Breus 2012) and could, therefore, be used to build a predictive germination tool for future ecotoxicological assessments. Based on our experimental data it can be concluded that no toxicity symptoms were detected on plants grown in the pot experiment.

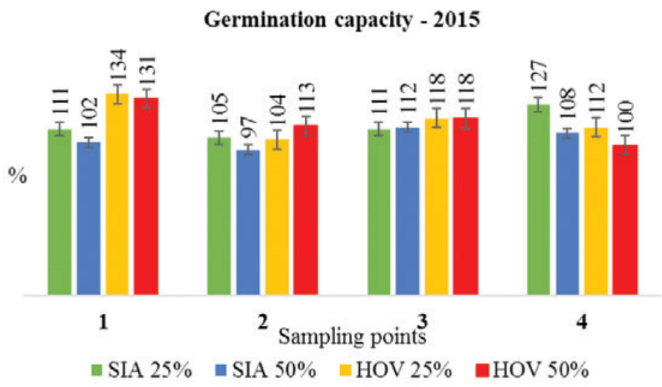

Fig. 4. Germination capacity in 2015

CONCLUSIONS

Landfills may pose serious threat to groundwater resources and soil. Following the experiments, on the germination capacity for white mustard (*Sinapis alba* L.) and for barley (*Hordeum vulgare* L.) the toxicity of soil sampled from the Zdounky-Kuchyňky landfill and its surrounding was determined. The present research showed that an increase in plant biomass for both years (2014 and 2015) was observed in plants growing in earthen pots with soil samples taken from the landfill body and landfill vicinity, but no changes in appearance, slow growth or necrotic lesions appeared. There was no evidence to suggest that the landfill has a significant impact on soils and on the biotic composition of the environment, no toxicity symptoms were detected on plants grown in the pot experiment that would have indicated the direct impact of sanitary landfill operation on the locality.

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