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DOES THE ADDITION OF SOIL AMENDMENTS HAVE A POSITIVE INFLUENCE ON LANDFILL SOILS?

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Abstract. Waste disposal in landfills is one of most frequently used methods of municipal solid waste (MSW) management. Landfills disturb to a certain extent the landscape character and disposal of waste in landfills represents one of human activities that may impair natural ecosystems. Due to waste decomposition, numerous chemical, physical and biological reactions and changes occur within the landfill body that give rise to dangerous and harmful substances. One of the problems very often occurring in the landfill surrounding is soil contamination. This study is focused on the assessment of soils contamination due to the operation of sanitary MSW landfill. The aim was to determine the effect of diatomite and compost on soil phytotoxicity. Toxicity was assessed in a pot experiment with soil amendments. Soil samples (sample 1–4) for the experiment were taken from the landfill site (sample 1–3) and its surrounding (sample 4). The aim of this study was to check relation between soil amendments added to the soil sample and the amount of biomass produced by some plant species (*Sinapis alba* L., *Hordeum vulgare* L.). In this study soil amendments improved soil characteristics. The paper shows that a higher percentage of biomass

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weight increase was recorded in samples 1, 2, 3 and 4 with the addition of compost. As compared with the addition of diatomite, biomass weight in the samples with the added compost increased on average by 67.25%. Therefore, it can be stated that the addition of diatomite did not advance the plant growth as much as the addition of compost. The potential of using soil amendments in practice is promising.

Keywords: soil contamination, soil amendments, soil phytotoxicity, landfill

INTRODUCTION

The living standard of people is improving which leads to the increasing production of waste. A great amount of waste is produced in the world every day (Voběrková *et al.* 2017). A man produces ca. 1.2 kg of waste daily. On a global scale, this represents a total production of 1.3 billion tons of MSW per year. This amount is expected to grow further and it is assumed that annual MSW production will reach 2.3 billion tons by 2025 (Caicedo-Concha *et al.* 2016).

One of waste management methods is disposal in landfills. Integrated solid waste management (SWM) makes use of sources from the waste by recycling or composting (Bhatt *et al.* 2017). Waste disposal in landfills is one of most frequently used methods of MSW management (Gworek *et al.* 2016). Landfills disturb to a certain extent the landscape character and disposal of waste in landfills represents one of human activities that may impair natural ecosystems (Gworek *et al.* 2016, Wong *et al.* 2016). Approximately 80% of global MSW production is disposed in landfills. Only 20% of this amount is contained in engineered and controlled landfill sites (Caicedo-Concha *et al.* 2016). In general, it holds that the amount of waste disposed in landfills should be reduced and treated in another way. In the Czech Republic (CR), the establishment of new landfill sites is not allowed. The existing landfill sites can only be extended. Due to waste decomposition, numerous chemical, physical and biological reactions and changes occur within the landfill body that give rise to dangerous and harmful substances (Koda *et al.* 2015). Leachates from landfills contain high amounts of heavy metals and represent a potential risk of contamination to soil, groundwater, plants, etc. (Gworek *et al.* 2016). One of the problems very often occurring worldwide is soil environment contamination (Feng *et al.* 2018).

Shakoor *et al.* (2017), Rivera *et al.* (2016), Cheng *et al.* (2014) and other authors inform that heavy metals are, to a certain extent, contained in the soil naturally (geogenic origin). However, they are present in the soils also due to human activities (anthropogenic origin) (Gąsiorek *et al.* 2017, Shen *et al.* 2017, Li and Ji, 2017, Jiang *et al.* 2017, Mehr *et al.* 2017). Soil is an accumulator of heavy metals and other pollutants and the concentration of these substances in the soils can be extremely high (Wang *et al.* 2005, Lough *et al.* 2005, Lin *et al*. 2005). Motor traffic can be a source of soil pollutants, too (Dao *et al*. 2014). Heavy metals are harmful to human organism and their accumulation in the environment is potentially dangerous (Adrees *et al*. 2015). Consequently, it is imperative to remediate those soils contaminated by heavy metals (Feng *et al*. 2018).

Many research works deal with possible methods of remediation of harmful substances in the environment such as soil washing or addition of immobilizing agents (zeolite, diatomite, CaO, apatite, peat, fly ash, chalcedonite, dolomite, limestone, activated carbon, biochar and compost). Amendments to contaminated soils represent another method of soil improvement. Soil amendments improve physical characteristics of soils, minerals are bound on the soil surface, soil reaction (pH) becomes stabilized, sorption capacity of the soil is enhanced and significantly affects the metabolism of plants (root growth stimulation, support to plant growth and branching). Soil amendments can also bind metal elements hence improving soil quality. As immobilizing agents, it is possible to use, for example, humus substances.

Yet another method for the remediation of the environment dwells on the use of plant species because some of them have a capacity of phytoremediation, i.e. accumulate contaminants in biomass. Phytoremediation is a low-cost, reliable and promising method for eliminating soil contamination. Plants are capable of accumulating a wide range of pollutants (inorganic substances, heavy metals, persistent organic pollutants and even radioactive elements) (Pandey *et al.* 2016, Yao 2017). The plants are placed in the contaminated soil; soil pollutants are bound by the plants and accumulated in their shoot parts. Subsequently, the plants are removed from the locality and the soil is cleaned (Linger *et al.* 2002). Risks of pollutants and complex mixtures for the environment are assessed by ecotoxicological methods (Aziz *et al.* 2004, Morozesk *et al.* 2016). Environmental risks need to be analysed and phytotoxicity needs to be evaluated. An easy and fast method to prove phytotoxicity is bioassay, which uses the method of germination of plants and determination of biomass (*Sinapis alba* L., *Hordeum vulgare* L., etc.). The test is based on the capacity of the tested substance to inhibit germinating capacity of seeds and growth of biomass (Reijs *et al.* 2003).

This study is focused on the assessment of soils contamination due to the operation of MSW landfill located in the Czech Republic (49°24'90.778"N, 17°31'21.181"E). The aim was to determine the effect of diatomite and compost on soil phytotoxicity. Toxicity was assessed in a pot experiment with soil amendments. Soil samples for the experiment were taken from the landfill site and its surroundings. The method is to check relation between soil amendments added to the soil sample and the amount of biomass produced by some plant species (*Sinapis alba* L., *Hordeum vulgare* L.).

MATERIALS AND METHODS

Study area – landfill site description

The study area is located in the Zlín Region, eastern part of the Czech Republic. The Zdounky (Kuchyňky) landfill (49°24'90.778"N, 17°31'21.181"E) is classified in the S-category for "other waste"; hazardous waste is not being deposited in the landfill (Fig. 1). The landfill, which has been in operation since 1995 is sized 70,700 m^2 and is divided into five stages. Its total capacity is 907,000 m^3 of waste, which corresponds to the weight of ca. $1{,}000{,}000 \cdot 10^3$ kg. The landfill is used for waste brought from the nearby surroundings with ca. 75,000 inhabitants. Total annual amount of waste deposited in the landfill is almost $40{,}000 \cdot 10^3$ kg with municipal waste constituting a half (Voběrková *et al*. 2017).

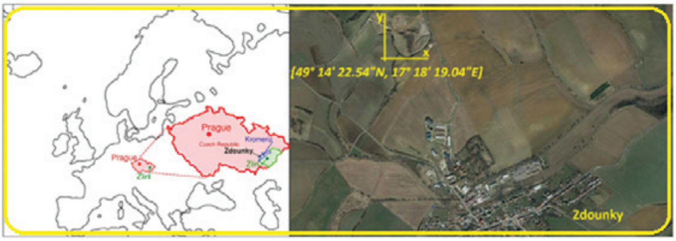

Fig. 1. Location of Zdounky (Kuchyňky) landfill and surrounding region

Soil sampling

The soil was sampled from four sampling sites (Fig. 2.) into sterile plastic containers. Samples 1–3 (sample 1: 49°14'29.072"N, 17°18'22.617"E, sample 2: 49°14'28.240"N, 17°18'27.136"E, sample 3: 49°14'26.626"N, 17°18'24.780"E)

Fig. 2. Sampling points

were taken from the landfill body and sample 4 (sample 4: 49°14'32.728"N, 17°18'13.386"E) was taken from a site adjacent to the landfill (crossing of access road to the landfill with the main communication). The sampling was made by using hoe and spade. The amount of earth taken from each site for the test was identical in each sample (2 kg±0.1 kg). The samples were brought to the laboratory where they were dried at laboratory temperature, coarse foreign bodies were removed, and the samples were then sifted through a sieve of 2 mm mesh size (according to the ČSN ISO 11464 (836160) – "Soil quality – Pre-treatment of samples for physico-chemical analyses"). Thus treated fine earth samples were then stored in sampling bags for bioassay tests (Hrbáčková 2018).

Soil amendments

The test is based on the cultivation of seeds of the given plant (e.g. *Sinapis alba* L.) in the samples of studied soils. It is useful to use plants sensitive to toxic substances in the test. Soil amendments in given concentrations were added to the earth samples. Figure 3 presents soil amendments (compost and diatomite) chosen for the experiment.

Diatomite is a loose, fine-grained up to clayey rock material. It is formed of diatom shells and its colour is white to creamy. Diatomite is a source of silicon (Si). Thanks to the supply of silicon, plants become more resistant to infections and stress. Moreover, they become more resistant to harmful effects of heavy metals, namely manganese and aluminium (Dessalev *et al*. 2017). Compost is emerging from the transformation of organic materials (cut grass, leaves, branches, etc.) during the process called composting. In this process, organic substances become decomposed in the composting materials and change into stable humus substances – compost. This material provides a range of required nutrients to plants. Compost is often used as growth media, organic fertilizer and soil amendment (Luo *et al*. 2018).

Fig. 3. Soil amendments; A – diatomit; B – compost

For testing the soil samples with the added soil amendments, we selected seeds of white mustard (*Sinapis alba* L.) and seeds of common barley (*Hordeum vulgare* L.). To the soil samples of 200 g in weight, there were added 3 g of soil amendments. Samples from each sampling site were treated by blending 200 g of soil with 3 g of diatomite and by blending 200 g of soil with 3 g of compost. The samples prepared in this way were inserted in containers. Seeds (100 pcs) of white mustard (*Sinapis alba* L.) were put on the surface into each container and covered with silica sand. The same experiment was repeated with the common barley (*Hordeum vulgare* L.) seeds. The test was performed in three repetitions. Reference sample were soil samples from the respective sampling sites without the soil amendments. The containers were kept in the laboratory conditions at a temperature of 20°C (±2°C) in daylight and regularly moisturized with water. The experiment was brought to an end after 21 days and results were evaluated. The created biomass was taken from all containers and its weight was ascertained. Reference value was the weight of biomass produced on the reference substrate. Weights of biomass from the explored soil samples with soil amendments were compared with the reference soil samples without soil amendments. The comparison of biomass weights was expected to demonstrate the effect of soil amendments on soil quality and biomass growth in the experimental plants (Hrbáčková 2018).

RESULTS

Thanks to the soil amendments added to the samples of tested soils, biomass increase was observed in both experimental plants. Total biomass weight from the experimental containers with the soil amendments increased as compared with the reference samples. Results of biomass weight from the respective sampling sites (1–4) for the two experimental plants are presented in Table 1.

Biomass weight of white mustard (*Sinapis alba* L.) in the reference samples ranged from 1.6 to 3.4 g. In the experimental samples with the soil amendments – compost, biomass weight increased to 6.3 g. In sample 4, where diatomite was added together with compost, biomass decrease was observed. In reference sample 4, the lowest biomass weight (1.6 g) was recorded. In this case, soil improvement with the two soil amendments did not result in biomass weight increase.

Biomass weight of common barley (*Hordeum vulgare* L.) in the reference samples ranged from 2.7 to 10.2 g. The lowest biomass weight was recorded in reference sample 4 (2.7 g). Samples 1, 2, 3 and 4 exhibited biomass weight increase after addition of soil amendment (compost). Samples 1, 3 and 4 exhibited biomass weight increase after addition of soil amendment (diatomite). Only sample 2 exhibited biomass weight decrease by 1 g after addition of diatomite as compared with the reference sample.

Table 1. Increase in biomass after addition of soil amendments

Biomass	(g)	(g)
Sample 1	*Sinapis alba* L.	*Hordeum vulgare* L.
Reference	2.8	9.8
Soil + diatomit	3.0	11.8
Soil + compost	3.5	11.9
Sample 2	*Sinapis alba* L.	*Hordeum vulgare* L.
Reference	3.4	10.2
Soil + diatomit	4.0	9.2
Soil + compost	6.3	11.6
Sample3	*Sinapis alba* L.	*Hordeum vulgare* L.
Reference	2.7	3.0
Soil + diatomit	3.5	6.7
Soil + compost	5.4	9.0
Sample 4	*Sinapis alba* L.	*Hordeum vulgare* L.
Reference	1.6	2.7
Soil + diatomit	1.2	6.0
Soil + compost	1.5	10.5

Figures 4 and 5 illustrate biomass weight (expressed in percent) in samples 1, 2, 3 and 4 for the experimental plants after addition of soil amendments (diatomite and compost) as compared with the reference samples.

The results for white mustard (*Sinapis alba* L.) indicate that biomass weight increased after the addition of soil amendments (diatomite and compost) in samples 1, 2 and 3. Only sample 4 did not exhibit any percentage biomass increase but rather values lower than those of the reference sample (by 25% and 6% with the use of diatomite and compost, respectively). After the addition of diatomite, biomass weight in samples 1, 2 and 3 increased by 7–30%, on average by 18.3%. After the addition of compost, biomass weight in samples 1, 2 and 3

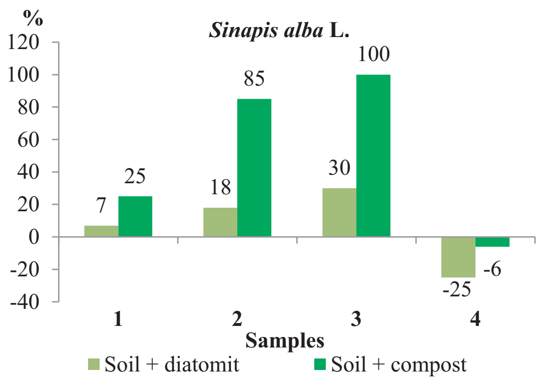

Fig. 4. Biomass of *Sinapis alba* L.

increased by 25–100%, on average by 70%. This shows that a higher percentage of biomass weight increase was recorded in samples 1, 2 and 3 with the addition of compost. As compared with the addition of diatomite, biomass weight in the samples with the added compost increased on average by 51.7%. Therefore, it can be stated that the addition of diatomite did not advance the plant growth as much as the addition of compost.

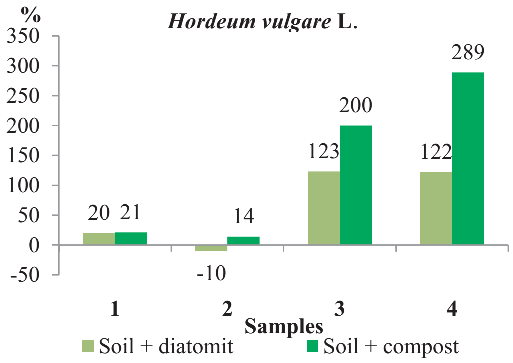

Fig. 5. Biomass of *Hordeum vulgare* L.

The results for common barley (*Hordeum vulgare* L.) indicate that biomass weight increased after the addition of soil amendments (diatomite and compost) in samples 1, 3 and 4. Only sample 2 did not exhibit any percentage biomass increase but rather values lower than those of the reference sample in the case of diatomite (by 10%); however, after the use of compost, biomass weight increased by 14%. After the addition of diatomite, samples 1, 3 and 4 exhibited biomass weight increased by 20–123%, on average by 88.3%. After the addition of compost, samples 1, 2, 3 and 4 exhibited biomass weight increase by 14–289%, on average by 131%. This shows that a higher percentage of biomass weight increase was recorded in samples 1, 2, 3 and 4 with the addition of compost. As compared with the addition of diatomite, biomass weight in the samples with the added compost increased on average by 67.25%. Therefore, it can be stated that the addition of diatomite did not advance the plant growth as much as the addition of compost.

DISCUSSION

Plants react to soil contamination with heavy metals very quickly and the use of methods based on phytotoxicity is effective in assessing the state of pollution (Białowiec 2015, Radić *et al.* 2018). One of the important elements of bioindication research is a quick and cheap diagnosis of the impact of adverse environmental changes. In addition, the introduction of new research methods to control the environment in the vicinity of landfills contributes to a more thorough, multifaceted analysis and broadens the possibilities of interpretation of research results (Białowiec 2015). It can also be an important supplement to the classic monitoring obligatory in municipal waste landfills. The conducted phytotoxicity tests showed the importance of this method, because they showed very large possibilities of shuffling the impact of pollution on organisms under the influence of pollution (Białowiec 2015).

As published by Vaverková *et al*. (2017), earth samples were taken in 2014 and 2015 from four sites on the landfill area in Zdounky (Kuchyňky). The soil samples were taken from the reclamated part of the landfill, from the nearest surroundings and from the crossing of the main communication with the access road to the landfill. The sampling points were identical with samples 1–4 in this research. In the laboratory conditions, the earth samples were subjected to the test of phytotoxicity with using the seeds of white mustard (*Sinapis alba* L.) and common barley (*Hordeum vulgare* L.). Methodology of the test was in compliance with the standard ČSN EN 13432. Soil samples from the landfill were at a concentration of 25% and 50% with the reference substrate. The experiment aimed at the assessment of germinating capacity. In 2014, germinating capacity of soil samples ranged from 100 to 111% for *Sinapis alba* L. and from 92 to 107% for *Hordeum vulgare* L. Soil samples from 2015 exhibited higher capacity of germination in the two experimental plants as well as in the two concentrations. The germinating capacity of *Sinapis alba* L. ranged from 97 to 127% and that of *Hordeum vulgare* L. ranged from 104 to 134%. Based on the data ascertained by Vaverková *et al*. (2017), the germinating capacity of the plants was not affected by any toxic and growth-inhibiting substances. In 2018, the germination of *Sinapis alba* L. was most inhibited after the addition of soil amendments in sample 4. The germination of *Hordeum vulgare* L. was most inhibited by adding diatomite to sample 2. The germination capacity of *Sinapis alba* L. in samples 4 (sampling site 4) was 102–107% in 2014 and 108–127% in 2015. The germination capacity of *Hordeum vulgare* L. in samples 2 (sampling site 2) was 92–95% in 2014 and 104–113% in 2015.

CONCLUSIONS

1. Landfills of municipal solid waste represent a significant disturbance of landscape character and a source of potential risks and pollution of the environment. Apart from the risk of the contamination of both surface and ground waters, they also represent a risk of soil contamination on the landfill site and its close surroundings.

2. Soil quality and health is a very important indicator for the sound functioning of ecosystems. Contamination of soils has a negative impact also on

human health because harmful substances may get into human bodies through the food chain where they may accumulate and cause serious health problems.

3. There are methods of both eliminating the contaminants from the soils and reducing their toxic effects. In addition to the method of eliminating some heavy metals from the soils by using some plants (phytoextraction), there is also a method of adding soil amendments into the contaminated soils.

4. Soil amendments can improve soil characteristics and restrain the impact of harmful substances on the environment. In this experiment, we demonstrated the effect of soil amendments on the amount of biomass produced by *Sinapis alba* L. and *Hordeum vulgare* L. with the exception of sampling points 4 and 2 where the experimental plants exhibited excessive sensitivity to the soil amendments and responded by decreased biomass production. The potential of using soil amendments in practice is promising.

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