

SEASONAL CHANGES AND TOXIC POTENCY OF LANDFILL LEACHATE FOR WHITE MUSTARD (*SINAPIS ALBA* L.)

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Abstract

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Landfills are the most broadly used methods for the disposal of municipal solid waste (MSW). Leachate can be contaminated with pollutants that may pose a threat to the landfill surrounding namely soil, groundwater and surface waters.. Examination of leachate composition is determinative in long-term impact of landfills on the environment and human health. Moreover, it is essential to assess such prior knowledge for prevention of negative outcomes. The evaluation of the seasonal changes of landfill leachate and rainwater composition is presented in this paper. Research samples of leachate and rainwater were collected from February till June of 2017 (still ongoing) and analyzed for pH, electrical conductivity, dissolved oxygen, series of trace elements, Subsequently the test of leachate toxicity for higher plants (*Sinapis alba* L.) was carried out. Up to now, the results do not indicate significant seasonal difference in landfill leachate composition, however the toxicity tests provided on *Sinapis alba* L. demonstrate that landfill leachates can present a significant source of contamination. This research can serve practical tools for evaluating quality and risk assessment for landfill leachate.

Keywords: waste, landfill, toxicity tests, pollution, *Sinapis alba* L.

INTRODUCTION

The oldest form of the removal and disposal of waste is landfilling (Vaverková *et al.*, 2013; Vaverková and Adamcová 2014; Koda *et al.*, 2015; Adamcová *et al.*, 2016a; Ghosh *et al.*, 2017) and landfills are broadly used methods for the disposal of MSW (Baderna *et al.*, 2011; Tsarpali *et al.*, 2012). Moreover, in the future, landfill will continue to be a major disposal option for MSW. This method of waste disposal are known source of environmental pollution (Hu *et al.*, 2017), and waste buried in landfill is subjected to a series of physico-chemical and biological transformations, generating

potentially polluted water–leachate (Ghosh *et al.*, 2017). Leachate may contaminate the groundwater as well as the surface waters (Gworek *et al.*, 2015; Li *et al.*, 2017). The composition of leachate is affected significantly by the type of landfill, the waste disposed, the degree of compaction, and water content (Koda *et al.*, 2015; Zhao *et al.*, 2017). It is defined by high concentrations of organic and inorganic compounds, derived mainly from the disposal of non-hazardous MSW, as well as toxic chemicals (Tsarpali *et al.*, 2012). If a waste has a high content of organic fraction, leachate is characterized by a higher oxygen content and higher

concentration of ammonium and organic nitrogen (Koda *et al.*, 2015). Generally, leachate from MSW landfill sites has the same composition: Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), volatile fatty, inorganic macro components like Ca^{2+} , Mg^{2+} , Na^+ , K^+ , NH_4^+ , Cl^- , SO_4^{2-} , HCO_3^- , trace elements and xenobiotic organic compounds (Ghosh *et al.*, 2017). But trace elements are the most toxic and/or problematic pollutants in leachate. Authors (Baun and Christensen 2004; Öman and Junestedt 2008; Renou *et al.*, 2008), suggested that typical trace elements concentrations in leachate are: Cd (0.0001-0.13 mg/L), Cr (0.0005-1.6 mg/L), Fe (0.08-2,100 mg/L), Mn (0.01-65 mg/L), Ni (0.03-3.2 mg/L), Pb (0.0005-1.5 mg/L), and Zn (0.00005-120 mg/L). The trace elements concentrations in young (acetogenic) leachate are usually higher than those in old (methanogenic) leachate (Kjeldsen *et al.*, 2002; Öman and Junestedt 2008; Oka *et al.*, 2017).

Commonly, assessment of leachate is based on identification of pollutants through chemical analyses (Ghosh *et al.*, 2017), however, evaluation of leachate can be based also on the interactions with biota (Kjeldsen *et al.*, 2002, Tsarpali *et al.*, 2012). Actually, chemical analysis gives results about landfill leachate composition/pollution, while the toxicological tests, integrates the effect of all contaminants, providing information on their bioavailable fraction (Pandard *et al.*, 2006; Kalcikova *et al.*, 2011; Tsarpali *et al.*, 2012).

From the literature view it can be concluded that papers usually contain only random leachate characterization (Wu *et al.*, 2004; Bila *et al.*, 2005; Kurniawan *et al.*, 2006; Laitinen *et al.*, 2006, Gworek *et al.*, 2015), however, toxicological evaluation of leachate to examine the impact of leachate discharged into the environment is rather rare. Only some authors have tried to characterize leachate composition during the landfill exploitation. Therefore, the purpose of this study was to

characterize the major components of leachate from MSW landfill, namely the landfill site in Zdounky-Kuchyňky (Czech Republic). To authors best knowledge, the seasonally variety of leachate is not well studied yet.

An experimental investigation was conducted to explore: (a) the trace elements concentrations in leachate, (b) the phytotoxicity of the leachate, (c) the effects of leachate on root growth inhibition of *Sinapis alba* L. and, (d) the seasonal alterations of leachate toxicity. Additionally, rainwater characterization was also defined. Moreover, this study is a part of the long-term research of landfill Zdounky-Kuchyňky and its influence on the environment.

MATERIALS AND METHODS

Landfill site description

The Zdounky-Kuchyňky landfill (49.2490778 N, 17.3121181 E) (Fig. 1) is an active and sanitary (with leachate protective layer) landfill site located in the Czech Republic (CR). The landfill activity started in 1995. It is situated in a triangular space delimited by main roads connecting the villages of Zdounky, Nětčice and Troubky-Zdislavice (Vavřková *et al.*, 2012). The designed area of the landfill is 70,700 m² with a total volume of 907,000 m³, i.e. ca. 1,000,000 10³ kg of waste. The planned service life of the facility is up to 2027. The landfill receives waste from a catchment area with a population of around 75,000 residents. The annually deposited amount of waste is around 40,000·10³ kg (50% is from the communal sphere, non-hazardous waste including MSW). The surrounding is bordered by agricultural fields. The leachate is collected via a draining system and stored in leachate pond (receiving system) (Vavřková *et al.*, 2012).



1: Map of the case-study landfill Zdounky-Kuchyňky (adapted from Google Maps Data).

Leachate sampling

Leachate and rainwater samples were collected from February till June of 2017 (still ongoing). The sample of the leachate and rainwater were not collected in January (2017) because the ponds were frozen. The frequency of leachate and rainwater sampling from leachate pond and rainwater pond was one time per month. Two samples (0.5 L/sample) of leachate (leachate pond) and rainwater (rainwater pond) (Fig. 2) were collected in sterile collection containers. Samples were stored at 4 °C and transported to the analytical laboratory at the Department of Chemistry and Biochemistry, Faculty of AgriSciences, Mendel University in Brno for analysis within 72 h. Leachate and rainwater samples were analyzed for pH, electrical conductivity (EC), chemical oxygen demand (COD) *in situ* using a Multi-Parameter Meter HQ30d Portable and series of analyses of trace elements (Cd, Cr, Ni, Pb, Zn, Hg) *ex situ*.

Phytotoxicity test

White mustard (*Sinapis alba* L.) was used as a test organism to assess toxicity of leachate and rainwater samples. *Sinapis alba* L. is ideal for studying toxicity because it is sensitive to board range of chemicals. The effect of toxicity was assessed based on physiological (germination energy and germination) and morphological traits (root length) of white mustard (*Sinapis alba* L.). The treatments consisted of different concentrations of 25%, 50%, 75% and 90% (three replicate samples). Concentrations of leachate and rainwater has been chosen on the basis of authors previous experiments and studies (Vaverková *et al.*, 2017). The test organisms were germinated in petri dishes and exposed to the leachate and rainwater solutions for a total of 72 h. The hydroponic solution (distilled

water with the following chemical ingredients (mg/L): $\text{Ca}(\text{NO}_3)_2$ 0.8, KH_2PO_4 0.2, KNO_3 0.2, $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$ 0.2, KCl 0.2, FeSO_4 0.01, pH = 5.2) with tested liquid was added into each dish, and 15 healthy looking seeds of similar size were evenly spread onto the surface of the filter paper. The petri dishes were covered by a glass cap to prevent loss due to evaporation and were located in the EcoCell thermostat ($t = 24^\circ\text{C}$, air humidity 80%, dark environment). The root length were recorded at the end of the 3rd day (Fargašová 2004; Adamcová *et al.*, 2016b; Vaverková *et al.*, 2017).

Calculations and Data analysis

The analyses and the length measurements were performed using the Image Tool 3.0 for Windows (UTHSCSA, San Antonio, USA). The percent of root growth inhibition (RI) were calculated with the formula (Eq. 1):

$$\text{RI} = A - B/A \times 100 \quad (1)$$

Where: A means root length in the control; B means root length in the test (Adamcová *et al.*, 2016b).

RESULTS AND DISCUSSION

Chemical characteristics of landfill leachate and rainwater

Chemical characteristics of leachate are summarized in Tab. I and Tab. II. Investigated landfill leachates showed similar characteristics to the leachates sampled in other MSW landfills (Kulikowska and Klimiuk 2008; Guo *et al.*, 2010; Kalčíková *et al.*, 2014). The pH of leachate was 8.03 and demonstrated that the leachate was alkaline and that the landfill is already in methanogenic phase of life cycle. It can be concluded that most of the chemical substance in the leachate is basic



2: Leachate pond and rainwater pond.

I: Trace elements concentrations in leachate

Leachate	Trace element	Cd	Pb	As	Cr	Ni	Zn	Hg
Month	Unit	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
February	Concentration	0.179	11.32	12.54	74.33	34.84	0.0652	0.00306
	SD%	33.5	0.6	0.7	1.3	2.8	4.1	0.164
March	Concentration	0.373	3.299	11.55	59.3	70.29	0.0251	0.00045
	SD%	24.7	24.5	1.1	27.8	13.9	8.3	0.001
April	Concentration	0.237	6.448	17.56	442.68	135	0.0787	0.0023
	SD%	26.1	6.3	14.2	30.7	11.6	1.3	0.048
May	Concentration	0.518	15.262	4.5	108.19	155	0.4723	0.00393
	SD%	33.1	5.4	28.2	20.6	5.7	0.7	0.005
June	Concentration	<LOD	5.282	35.91	325.72	139.22	52.6	0.64
	SD%		14	5.6	0.9	0.2	1.2	0.001

*Standard deviation (SD)

**Limit of detections (LOD)

II: Main chemical properties of the leachate

Parameters	February	March	April	May	June
COD (mg/L)	2.38	0.99	1.69	0.13	2.92
pH	7.35	7.6	7.92	8.7	8.61
EC (µS/cm)	2.65	6.12	12.79	10.87	11.69

*Chemical oxygen demand (COD)

**Electrical conductivity (EC)

III: Trace elements concentrations in rainwater

Rainwater	Trace element	Cd	Pb	As	Cr	Ni	Zn	Hg
Month	Unit	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
February	Concentration	<LOD	6.57	<LOD	8.48	2.18	0.033	0.00056
	SD%		0.7		25.4	0.7	11.9	0.018
March	Concentration	<LOD	1.766	<LOD	5.45	9.88	0.011	0.00057
	SD%		27.9		5.9	6.1	7	0.002
April	Concentration	<LOD	2.591	1.16	<LOD	2.7	0.0165	0.00133
	SD%		18.7	1.3		31.1	4	0.02
May	Concentration	<LOD	2.091	0.74	1.06	5.73	0.0091	0.00203
	SD%		0.8	21.4	22.9	25.8	5.9	0.004
June	Concentration	<LOD	<LOD	1.18	9.75	4.37	10.7	0.93
	SD%			4.8	4.8	8.3	3.9	0.001

*Standard deviation (SD)

**Limit of detection (LOD)

IV: Main chemical properties of the landfill rainwater

Parameters	February	March	April	May	June
COD (mg/L)	10.16	9.37	10.02	8.56	9.18
pH	8.65	7.71	7.99	7.97	7.9
EC (µS/cm)	1281	1244	1217	1181	1209

*Chemical oxygen demand (COD)

**Electrical conductivity (EC)

in nature. The pH of Zdounky-Kuchyňky leachate was in agreement with other sanitary landfills for example in with Jeram's landfill Malaysia; Ampar Tenang, Malaysia; Rio de Janeiro, Brazil and Casone, Italy in which the pH fell within the range of 7.36-8.80 (Isidori *et al.*, 2003; Silva *et al.*, 2004; Alkassasbeh *et al.*, 2009; Budi *et al.*, 2016).

Relatively low trace elements concentrations are suggesting that Zdounky-Kuchyňky leachate does not represent a significant trace elements hazard. These low values of trace elements in leachate were in agreement with sanitary landfills in Sweden and Brazil (Silva *et al.*, 2004; Öman and Junestedt 2008).

The concentration of Hg and Pb over a given period of leachate samples was stable, with an increase in concentrations of trace elements As, Cr, Ni, Zn and Hg. The highest concentrations were recorded for trace elements: Cr, Ni and Zn. The lowest concentrations were recorded for Cd, Pb and As.

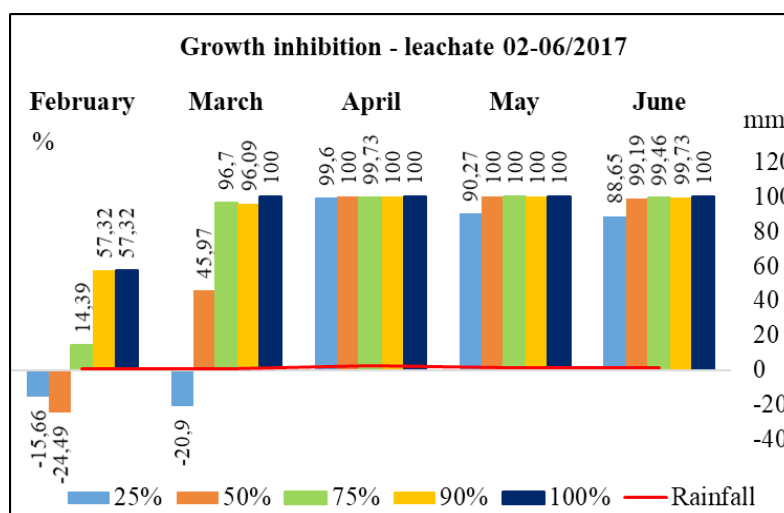
It can be concluded that with the passage of time and with seasonal changes values of various

parameters (trace elements) in leachate increased, the main reason is that the solid waste material degraded with time and the waste constituents percolated down along with rainwater. Moreover, the age and seasonal changes (like precipitation) has an important effect on leachate composition. However, it was observed that trace elements concentration in rainwater in time decreased. Chemical characteristics of Zdounky-Kuchyňky rainwater are summarized in Tab. III and Tab. IV.

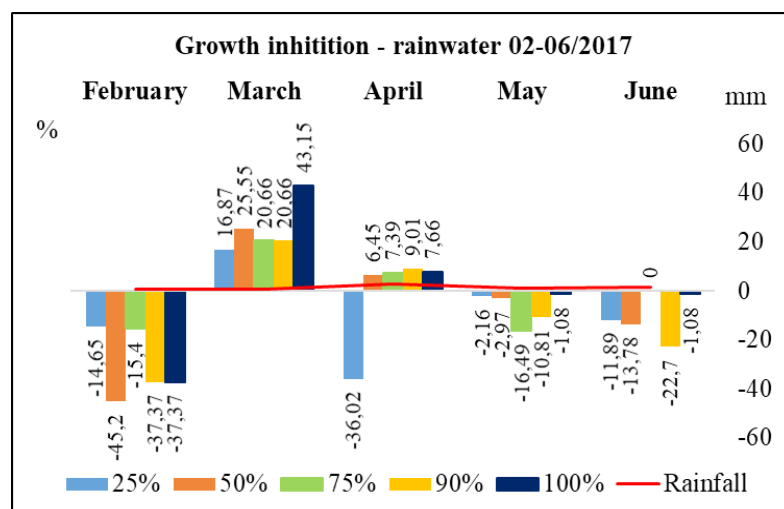
The concentration of Cd, Pb, As, Cr, Ni, and Hg over a given period for rainwater samples was constant, with a significant decrease in the concentration of Zn. However, the concentration of Zn was the highest.

Plant growth inhibition

The germination of crop plants was tested using the hydroponics medium supplemented with leachate and rainwater 25%, 50%, 75%, 90% and 100%. The number of germinated seeds was compared with the control. Results are expressed as



3: Growth inhibition-leachate



4: Growth inhibition-Rainwater

mean \pm standard deviation (SD). The average rainfall for the given period was 89.72 mm (February–June).

The image of the growth inhibitions of *Sinapis alba* L. leachate samples for months February, March, April, May, June (concentration 25 %, 50 %, 75 %, 90 % and 100 %) are shown on Fig. 3. Leachate samples for those months were toxic. The growth inhibition values for sample February ranged from - 24.49 % to 57.32 %, which is the lowest growth inhibition of all tested samples. The results reveal that the growth inhibition for sample March, April, May, June (concentration 25 %, 50 %, 75 %, 90 % and 100 %) were toxic likewise (average value 89.72 %). With increasing leachate concentrations, the examined samples showed higher values of growth inhibition. These results provide reference data for risk assessment and the management of leachate.

Leachate may contain a wide range of inorganic, natural and xenobiotic compounds, the mixture of which can affect the plant growth (Zhang *et al.*, 2013). It was found that leachate at higher levels (concentrations) can severely inhibit plant growth, whereas leachate at lower levels (concentration 25 %) can stimulate growth. It is reported that leachate at high levels could lead to a yield reduction and poor survival rate (Menser, 1981; Menser *et al.*, 1983); however, the leachate at low levels (concentrations) enhanced the growth, survival and stomatal conductance of plants (Liang *et al.*, 1999; Sang and Li 2004; Sang *et al.*, 2006; Li *et al.*, 2008; Zhang *et al.*, 2013).

The image of the growth inhibitions of *Sinapis alba* L. rainwater samples for months February, March, April, May, June (concentration 25 %, 50 %, 75 %, 90 % and 100 %) are shown on Fig. 4. The results show that the growth inhibition (%) for rainwater samples–February, April, May, June (concentration 25 %, 50 %, 75 %, 90 % and 100 %) compared to leachate

were not toxic. The growth inhibition values for sample March ranged from 16.87 % to 43.15 %, which is the highest growth inhibition of all tested samples. The growth inhibition values for sample February ranged from -14.65 % to -45.2 %, which is the lowest growth inhibition of all tested samples.

It is worth to mention that previous studies have confirmed that bioassays eliminate the limitations of classical chemical analyses (Ghosh *et al.*, 2017) and that higher plants might be helpful for screening and monitoring of environmental contaminants.

Experimental studies on the phytotoxicity of leachate have reported both positive and detrimental effects on plants (Zhang *et al.*, 2013). The toxicity of leachate was investigated by a numerical study. Bortolotto *et al.* (2009) evaluated Southern Brazil landfill leachates toxicity using *A. cepa* as an indicator species. In this study the untreated leachate resulted in a significant inhibition of root growth, whereas the treated leachate did not show a significant toxicity. Authors concluded that the leachate treatment caused the reduction in toxicity observed in *Artemia* sp. toxicity assays (Bortolotto *et al.* 2009).

Results of the present toxicological assessment of leachates showed that their quality are inconsequential during the study period (February–June 2017). However, interestingly, this is contrary to a study conducted by Sang and Li (2004). They reported that leachate toxicity varies seasonally while working with *Vicia faba* as a model test organism. In this study authors observed severe genetic damages in *V. faba* in case of leachate depending on the season (cold and dry season compared to the hot and rainy season) owing to seasonal changes in the concentrations of contaminants in the leachates (Sang and Li 2004).

CONCLUSION

The current study contributes to our knowledge about chemical parameters, toxicity and/or pollution of leachate during various seasons of the year to achieve an appropriate assessment of its environmental impact. It can be concluded that with the passage of time values of trace elements in landfill leachate increased. However, trace elements concentration in rainwater in time decreased. Furthermore, results of the present toxicological assessment of leachate showed no significant changes in leachate toxicity during the study period (February–June 2017). The second major finding was that leachate at higher levels (concentrations) can heavily inhibit plant growth, whereas leachate at lower levels (concentrations) can stimulate growth. Based on the results it is recommended that further research be undertaken in the evaluation in leachate toxicity.

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