EKOLOGIJA. 2007. Vol. 53. No. 1. P. 98–107

Remediation of landfill soils with sewage sludge
2. Microarthropod communities in the soil formation process

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Remediation of buried and destroyed soils is one of the most relevant ways to preserve terrestrial ecosystems. Application of sewage sludge for landfill remediation is a good solution of two problems: sewage sludge utilization and landfill remediation. However, it should be borne in mind that the intensity of soil formation directly depends on the amount of introduced organics and pedobiont activity.

Investigations revealed that after nine years of remediation with sewage sludge, landfill soils contain up to 6.0% of humus and are most highly polluted with zinc (360.5 mg/kg) and chromium (106.0 mg/kg). In the mentioned time span, the concentrations of most heavy metals reduce to 2.4 times. The concentrations of heavy metals during landfill remediation with sewage sludge do not inhibit microarthropod successions in the soil. A certain equilibrium sets among the microarthropod groups, though euribiont species (*Tectocepheus velatus*, *Isotoma notabilis, Mesophorura gr. armata*) are dominant. Landfill soil and grass are most highly polluted with zinc. Zinc is also the main pollutant accumulated by grasses in the peripheral part of a landfill.

Key words: landfill, peripheries, heavy metals, microarthropods, sewage sludge

INTRODUCTION

The ever increasing amounts of accumulated sewage sludge near urban settlements and expanding areas of destroyed soils which may be remediated by organic matter, could contribute to the solution of two interrelated ecological problems – utilization of waste organics and remediation of soils.

The possibilities of application of sewage sludge are widely discussed. Many works are devoted to the effects of sewage sludge on the physico-chemical properties of soil and on biological processes taking place in it (Smith, 1991; Franzluebbers et al., 1995; Berti, Jacobs, 1996; Rice et al., 1996; Bagdanavičienė, Ramanauskienė, 1997; Eitminavičiūtė, 1997; McBridge et al., 1997; Stamatiadis et al., 1999; Brazauskienė et al., 2006). Attention is mainly focused on the impact of heavy metals on soil biota and the ability of biota to accumulate and detoxify heavy metals and their compounds (Larsen et al., 1996; Bruce et al., 1999; Marino, Morgan, 1999; Spurgeon, Hopkin, 1999; Eitminavičiūtė et al., 2002).

There are more than 800 landfills of different size and many exhausted gravel, sand and clay quarries in Lithuania. These destroyed or buried soils can be remediated using organic matter. When a substratum poor in organics substratum is used for remediation of landfills, the soil formation process is very slow (Eitminavičiūtė, 1998).

Based on abundant data, we made an attempt to analyse the soil formation process in landfills remediated with sewage sludge, i. e. to elucidate zoocoenostic successions and to evaluate the toxicity of these soils to biota.

The present work is a sequel of previous investigations of sewage sludge used for soil remediation and its capacity to intensify soil formation. It contains an evaluation of the impact of pollutants contained in sewage sludge, on the soil self-cleaning capacity and on biota. Reported data on the biological processes in forming soils are very poor (Eitminavičiūtė et al., 2005). Investigations of sewage sludge utilization are relevant from both the practical and scientific points of view.

MATERIALS AND METHODS

The Nemenčinė landfill is situated in the north-eastern periphery of the Nemenčinė borough on the left side of the Vilnius–Nemenčinė–Švenčionys, highway. The landfill occupies an area of 2 ha. It borders on a pine forest, a drained meadow and the Nemenčinė settlement. The landfill was remediated in 1997 with 450 t/ha of sewage sludge.

Investigations were started in 2002, i. e. in the fifth year after the introduction of sewage sludge, and lasted five years (2002–2006). The study material was taken in spring (May) and autumn (September) at two stationary sites: in the landfill and in the forest outskirts right behind the ditch surrounding the landfill, following the standard zoological methods for soil (Engelmann, 1978; Гиляров, Стриганова, 1987).

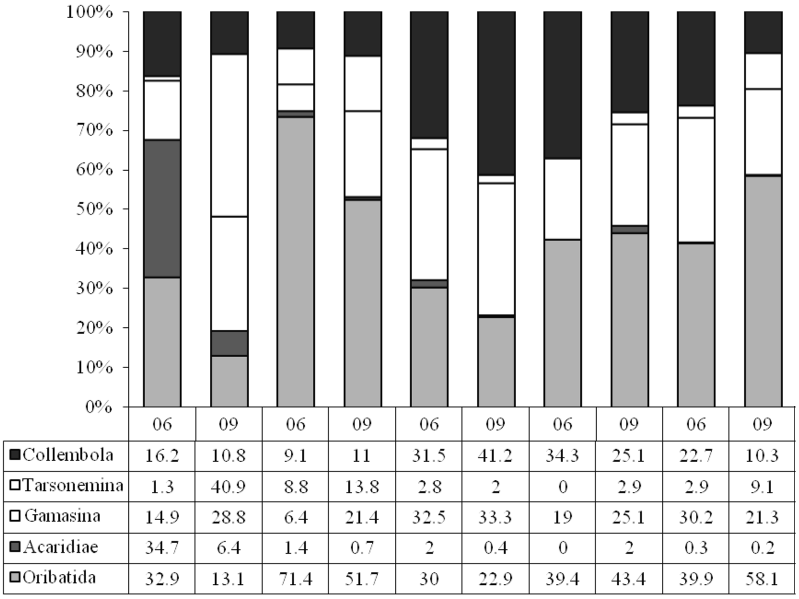
The physico-chemical properties (pH, moisture, temperature, concentration of heavy metals and biogenic elements) of the landfill and its peripheries, the concentration of heavy metals in the grass cover, and the successions and communities of microarthropods were analysed.

Analysis of heavy metals in the wastewater sludge, soil, plants was made using PerkinElmer atomic absorption spectrometers in the wastewater laboratory of the "Vilniaus vandenys" company.

Statistical data were processed using Microsoft Excel (Čekanavičius, Murauskas, 2000).

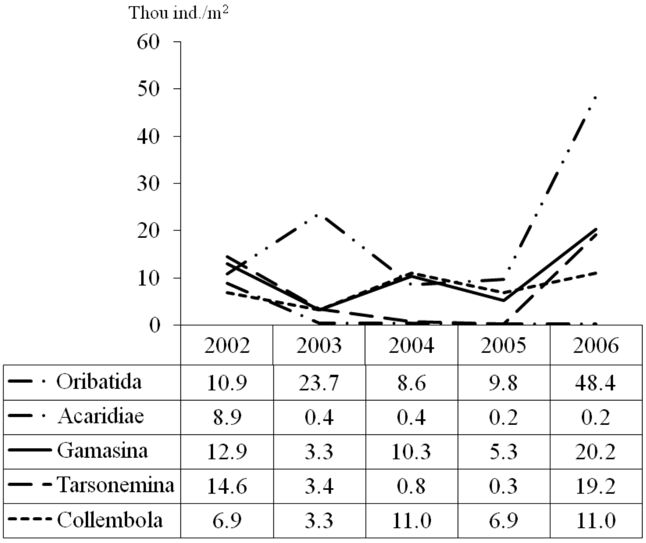
RESULTS AND DISCUSSION

Remediation of soil with sewage sludge is always related with some risk. Soil formation, the character of biological processes in it and its self-cleaning capacity directly depend on soil biota and its complicated trophic links. It has been proved that the structure of pedobiont complexes and species composition not only indicate the type of soil and ecosystem, but also reflect the ecological status of the soil, i. e. provide its ecotoxicological



	06	09	06	09	06	09	06	09	06	09
■Collembola	16.2	10.8	9.1	11	31.5	41.2	34.3	25.1	22.7	10.3
□Tarsonemina	1.3	40.9	8.8	13.8	2.8	2	0	2.9	2.9	9.1
□ Gamasina	14.9	28.8	6.4	21.4	32.5	33.3	19	25.1	30.2	21.3
■Acaridiae	34.7	6.4	1.4	0.7	2	0.4	0	2	0.3	0.2
▨Oribatida	32.9	13.1	71.4	51.7	30	22.9	39.4	43.4	39.9	58.1

Fig. 1. Microarthropod succession in landfill soils in the 5th–9th years after remediation



	2002	2003	2004	2005	2006
— · Oribatida	10.9	23.7	8.6	9.8	48.4
— · Acaridiae	8.9	0.4	0.4	0.2	0.2
—— Gamasina	12.9	3.3	10.3	5.3	20.2
— - Tarsonemina	14.6	3.4	0.8	0.3	19.2
---- Collembola	6.9	3.3	11.0	6.9	11.0

Fig. 2. Abundance (thou ind./m^2) of microarthropod groups in landfill soil in the 5th–9th years of remediation with sewage sludge

Table 1. **Microarthropods species diversity in the soil of landfill remediation with sewage sludge (Nemenčinė, 2002–2006)**

Species	2002				2003				2004				2005				2006				Σ	
	05		09		05		09		05		09		05		09		05		09			
	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%	T.ind./m²	%
Oribatida																						
Tectocepheus velatus (Michael 1880)	4.6	36.5	3.1	24.8	10.0	50.8	3.9	52.7	6.6	27.3	3.0	18.3	6.1	42.7	2.8	23.3	4.7	25.5	24.7	38.9	69.5	34.5
Microppia minus (Paoli 1908)	0.1	0.8																			0.1	0.05
Oppiella nova (Oudemans 1902)	0.1	0.8	0.3	2.4	2.9	14.7			2.2	9.1	0.2	1.2	1.0	7.0	2.5	20.8	3.3	17.9	0.4	0.6	12.9	6.4
Trichoribates novus (Sellnick 1928)	0.2	1.6	0.1	0.8	0.6	3.0	0.4	5.4	0.8	3.3	0.1	0.6	0.1	0.7	0.4	3.3	0.4	2.2	0.2	0.3	3.3	1.6
Suctobelba sp.					0.3	1.5	0.1	1.4	0.1	0.4											0.5	0.2
Brachychthonius sp.									0.1	0.4					0.1	0.8					0.2	0.09
Oribatula tibialis (Nicolet 1855)									0.1	0.4							0.1	0.5			0.2	0.09
Punctoribates punctum (C. L. Koch 1839)					0.1	0.5			0.1	0.4									10.5	16.5	10.7	5.3
Galumna sp.											0.1	0.6							0.2	0.3	0.3	0.1
Epidamaeus sp.																	0.3	1.6			0.3	0.1
Oribatella calcarata (C. L. Koch 1836)																			0.1	0.1	0.1	0.05
Eupelops occultus (C. L. Koch 1836)																			1.4	2.2	1.4	0.7
Oribotritia loricata (Rathke 1799)																			0.2	0.3	0.2	0.09
Σ	6.2	49.2	7.6	60.8	5.1	25.9	1.6	21.6	12.2	50.5	9.8	59.8	6.5	45.5	5.4	45.1	7.0	37.8	15.1	23.4	76.5	37.6
	5.0	39.7	3.5	28.0	13.9	70.6	4.4	59.5	10.0	41.4	3.4	20.7	7.2	50.4	5.8	48.2	8.8	47.7	37.7	59.2	99.7	49.3
Number of species	4		3		5		3		7		4		3		4		5		8		13	
Gamasina																						
Ameroseius corbicula (Sowerby 1806)	0.1	0.8	0.3	2.4															0.3	0.4	0.7	0.3
Rhodacarelus silesiacus (Willmann 1935)	0.7	5.6			0.1	0.5											0.4	2.2	0.8	1.2	2.0	0.9
Pergamasus septentrionalis Oudemans 1902									0.3	1.2	0.5	3.0									0.8	0.4
Pergamasus misellus Berlese 1904																			2.8	4.4	2.8	1.4
Pergamasus sp.	0.2	1.6	0.5	4.0	0.2	1.0	1.2	16.2	1.6	6.6	2.3	14.0	0.4	2.8	0.6	5.0	0.3	1.6	2.8	4.4	10.1	5.0
Discourella modesta (Leonardi 1899)	0.1	0.8																			0.1	0.05
Dendrolaelaps sp.	0.1	0.8			0.1	0.5					0.2	1.2					1.5	8.1	3.0	4.7	4.9	2.4
Pachylaelaps sp.	0.2	1.6	0.3	2.4					0.1	0.4	0.1	0.6									0.7	0.3
Asca bicornis (Can. et Fanz. 1887)							0.1	1.4											0.6	0.9	0.7	0.3
Asca sp.													0.1	0.7	0.1	0.8					0.2	0.09
Hypoaspis vacua (Michael 1891)					0.2	1.0															0.2	0.09
Hypoaspis aculeifer (Canestrini 1883)			0.2	1.6															0.2	0.3	0.4	0.2
Dendrolaelaps angulosus (Willmann1936)			0.1	0.8																	0.1	0.05
Cheiroseius borealis (Berlese 1904)					0.1	0.5															0.1	0.05
Cheiroseius sp.															0.1	0.8					0.1	0.05

Table 1 (continued)

Veigaia nemorensis (C.L. Koch 1839)							0.1	1.4													0.1	0.05
Uropoda minima Kramer 1882											0.1	0.6	0.1	0.7			0.2	1.1			0.4	0.2
Uropoda orbicularis (Müller 1776)																	0.1	0.5			0.1	0.05
Alliphis siculus (Oudemans 1905)																	0.1	0.5	0.1	0.1	0.2	0.09
Amblyseius sp.																			0.1	0.1	0.1	0.05
Σ	6.2	49.2	7.6	60.8	5.1	25.9	1.6	21.6	12.2	50.5	9.8	59.8	6.5	45.5	5.4	45.1	7.0	37.8	15.1	23.4	76.5	37.6
	1.4	11.1	1.4	11.2	0.7	3.6	1.4	18.9	2.0	7.0	3.2	19.5	0.6	4.2	0.8	6.6	2.6	14.0	10.7	16.5	24.8	12.0
Number of species	6		5		5		3		4		5		3		3		6		9		20	
Collembola																						
Hypogastrura assimilis Krausbauer 1898	2.1	16.7	0.3	2.4	2.1	10.7	0.2	2.7											1.4	2.2	6.1	3.0
Hypogastrura mambridia					1.0	5.1							0.1	0.7							1.1	0.5
Hypogastrura sp.			0.1	0.8	0.3	1.5															0.4	0.2
Protaphorura gr. armata (Tullberg 1869)	2.1	16.7							0.7	2.9	0.7	4.3					0.3	1.6	0.9	1.4	4.7	2.3
Mesaphorura gr. krausbaueri Börner 1901	0.5	4.0	5.5	44			0.1	1.4	0.5	2.1	4.3	26.2	1.7	11.9	0.1	0.8	1.8	9.7	8.3	13.0	22.8	11.3
Isotomodes productus (Axelson 1906)	0.2	1.6																			0.2	0.09
Lepidocyrtus sp. 2	0.2	1.6											0.2	1.4	0.2	1.7			0.6	0.9	1.2	0.6
Lepidocyrtus sp. juv.							0.1	1.4													0.1	0.05
Stenaphorura quadrispina Börner 1901	0.1	0.8																			0.1	0.05
Isotomiella minor (Schaeffer 1896)	0.8	6.3	1	8					2.4	9.9	0.5	3.0	0.1	0.7	0.5	4.2	0.5	2.7			5.8	2.8
Isotoma sp. juv.	0.1	0.8							0.1	0.4	0.1	0.6	0.1	0.7					0.3	0.4	0.7	0.3
Isotoma notabilis (Schaeffer 1896)	0.1	0.8	0.5	4	1.3	6.6	0.2	2.7	6.9	28.5	4.2	25.6	3.4	23.8	4.4	36.7	2,7	14.6	2,5	3.9	26.2	13.0
Isotoma hiemalis Schött 1893													0.2	1.4							0.2	0.09
Isotoma bipunctata Axelson 1903																	1.1	5.9			1.1	0.5
Folsomia quadrioculata (Tullberg 1871)													0.1	0.7							0.1	0.05
Sphaeridia pumilis (Krausbauer 1898)			0.1	0.8	0.3	1.5	0.2	2.7	0.1	0.4			0.3	2.1			0.4	2.2	0.9	1.4	2.3	1.1
Sminthurinus aureus (Lubbock 1862)			0.1	0.8									0.3	2.1			0.2	1.1			0.6	0.3
Proisotoma minuta (Tullberg 1871)					0.1	0.5	0.6	8.1													0.7	0.3
Brachystomella parvula (Schaeffer 1896)									1.2	5.0											1.2	0.6
Bourletiella hortensis (Fitch 1863)							0.2	2.7													0.2	0.09
Neanura muscorum (Templeton 1835)									0.3	1.2					0.2	1.7			0.1	0.1	0.6	0.3
Anurophorus laricis Nicolet 1842																			0.1	0.1	0.1	0.05
Σ	6.2	49.2	7.6	60.8	5.1	25.9	1.6	21.6	12.2	50.5	9.8	59.8	6.5	45.5	5.4	45.1	7.0	37.8	15.1	23.4	76.5	37.6
Number of species	9		7		6		7		8		5		10		5		7		9		22	
Total	12.6	100	12.5	100	19.7	100	7.4	100	24.2	100	16.4	100	14.3	100	12.0	100	18,4	100	63,5	100	201	100
	19		15		16		13		18		14		16		12		18		26		55	

Table 2. **Physical-agrochemical characteristics of the soil of Nemenčinė landfill and its peripheries (450 t/ha of sewage sludge were introduced in 1997)**

Year after the beginning of remediation	Year	Month	Location	Temperature, °C			Moisture %	pH_{KCl}	Humus %	Soil layer thickness cm	Plant cover %
				Air	Topsoil	At a depth of 5–10 cm					
5	2002	05	Landfill	25.0	21.0	15.0				10–20	100
			Peripheries	25.0	19.0	15.0					
		09	Landfill	14.0	15.0	10.5				10–20	100
			Peripheries	14.0	14.0	10.5					
6	2003	05	Landfill	22.0	19.0	20.0	14.4	7.82		10–20	100
			Peripheries	18.0	18.0	17.0	7.3	6.34			
		09	Landfill	17.0	16.0	16.0	14.6	7.79		10–20	100
			Peripheries	17.0	16.0	15.0	10.8	5.95			
7	2004	05	Landfill	10.0	9.0	8.0				10–20	100
			Peripheries	10.0	12.0	11.0					
		09	Landfill	14.0	14.0	12.0	23.2	7.67	2.5	10–20	100
			Peripheries	14.0	14.0	11.0	17.0	6.25	1.72		
8	2005	05	Landfill	10.0	9.0	8.0	32.9	7.44	5.8	10–15	100
			Peripheries	10.0	10.5	11.0	12.8	6.09	1.4		
		09	Landfill	19.0	12.0	11.5	18.2	7.51	6.0	10–15	100
			Peripheries	19.0	14.5	10.0	11.1	5.95	2.5		
9	2006	05	Landfill	13.0	15.0	10.0	25.9	7.47	5.6	10–15	100
			Peripheries	13.0	10.5	10.0	13.2	5.8	2.3		
		09	Landfill	16.0	16.0	16.0	22.8	7.49	4.5	10–15	100
			Peripheries	16.0	16.0	15.0	12.5	5.15	2.9		

prospects (Pankhurst, 1997; Straalen van, 1997; Parisi et al., 2005). The soil is inhabited by abundance (in terms of individuals and species) of pedobionts. Groups or their populations most suitable for biotests must be selected. It is impossible to work out universal biotests. Microarthropods and earth-worms have been reported as the best ecotoxicological bioindicators (Andres, 1999; Barrera et al., 2001; Gardi et al., 2002; Gardi et al., 2003). During soil remediation with sewage sludge, microarthropods reproduce in greatest abundance (Eitminavičiūtė, 1997).

The obtained results showed that *Acaridiae* mites were dominant in the soil in the first year of remediation with sewage sludge (Eitminavičiūtė et al., 2005). Later on, their abundance reduced. In the fifth year, the abundance of *Acaridiae* equalled that of *Oribatida*. In the sixth year, *Acaridiae* only accounted for one percent and shortly disappeared. *Oribatida* were the only dominant group of microarthropods in the sixth year of remediation. They accounted for 61.5% of the total of microarthropods (Fig. 1).

In the seventh–ninth years, an equilibrium set in among the dominant microarthropod groups (*Oribatida, Gamasina, Collembola*). *Oribatida* accounted for 39%, *Gamasina* for 27% and *Collembola* for 27.5%. The abundance of *Oribatida* ranged from 8.6 thou. ind./m^2 (the seventh year) to 48.4 thou. ind./m^2 (the ninth year) (Fig. 2).

The abundance of acarids, which were dominant in the first stages of sludge disintegration, reduced in the course of soil formation from 8.6 thou. ind./m^2 (the fifth year) to 0.2 thou. ind./m^2 (the eighth and ninth years). The abundance of *Gamasina* ranged from 3.3 thou. ind./m^2 (the sixth year) to 20.2 thou. ind./m^2 (the ninth year). *Tarsonemina* belong to the group of ephemeral microarthropods and, depending on the microclimatic soil conditions, especially on moisture, may either disappear or reproduce in abundance. Their abundance in this time span ranged from 0.3 thou. ind./m^2 (the eighth year) to 14.6 and 4.2 thou ind./m^2 (the fifth and ninth years). The lowest abundance of *Collembola* equalled to 3.3 thou. ind./m^2 in the sixth year, whereas in the seventh year it rose to 11.0 thou ind./m^2. The same abundance remained in the ninth year.

In the fifth–ninth years of investigation, 13 species of *Oribatida*, 19 species of *Gamasina* and 22 species of *Collembola* were detected in the forming landfill soil. A total of 55 species of microarthropods was identified (Table 1). Notwithstanding the large number of species, this was a monodominant microarthropod community in which *Tectocepheus velatus* accounted for 34.5%, *Isotoma notabilis* 13.0% and *Mesophorura gr. krausbaueri* for 11.3%. *Gamasina* were identified in small abundance. Only *Pergamasus* sp. accounted for 5.0%. In the fifth–ninth years of investigation, many microarthropod species occurred only as solitary individuals. Thus, we may conclude that at the end of the initial intensive degradation process, when microorganisms and *Acaridiae* play the leading role (Eitminavičiūtė, 1997; Navickienė, 1997; Umbrasienė, 1997; Eitminavičiūtė et al., 2005) and humus formation begins, a monodominant

Table 3. **Concentration of heavy metals (mg/kg) in Nemenčinė landfill soil remediated with sewage sludge and in its peripheries**

Year after the beginning of remediation	Year	Month	Location	Cu	Pb	Zn	Ni	Cr	Cd
			Landfill						
1	1997			222.4	21.1	619.6	91.8	94.8	5.8
1–2	2002–2003*			135.5	40.4	612.5	87.3	36.8	7.7
5	2002	05		63.0	29.6	190.0	42.0	72.0	2.9
		09		136.0	30.8	400.0	64.4	104.0	4.7
6	2003	05		64.0	33.2	260.0	76.0	6.0	8.4
7	2004	05		125.2	19.7	330.0	74.7	343.7	
		09		29.3	<2	235.7	11.7	62.0	<0,1
8	2005	05		120.0	111.0	448.0	51.6	116.0	2.8
		09		108.0	30.0	1010.0	54.3	121.3	1.8
9	2006	05		150.0	25.0	273.3	46.0	78.7	1.3
		09		103.0	38.0	97.3	34.3	50.1	0.2
			Total average	99.8	39.7	360.5	50.6	106.0	3.2
				± 39.6	± 29.3	± 265.4	± 20.3	± 96.0	± 2.7
			Peripheries						
1–2	2002–2003*			7.7	12.9	32.5	23.6	11.7	3.8
5	2002	05		4.0	9.0	50.0	9.0	10.0	1.4
		09		3.3	14.0	23.0	25.0	6.6	2.5
6	2003	05		3.5	12.4	16.0	18.2	6.0	5.6
7	2004	05		36.5	5.7	36.2	29.5	90.0	<0,1
		09		0.8	<2	35.7	1.3	6.5	<0,1
8	2005	05		4.2	8.8	23.4	4.4	7.8	0.2
		09		6.3	9.4	26.0	5.6	19.0	<0,1
9	2006	05		65.7	7.3	43.3	30.4	28.8	<0,25
		09		74.7	11.0	28.0	2.9	31.3	1.1
			Total average	22.1	9.7	31.3	14.0	22.9	2.2
				± 29.4	± 2.7	± 10.8	± 11.8	± 27.0	± 2.1
			p < 0,05	0.0003	0.0233	0.0059	0.0005	0.0333	0.4867
MPC sand sandy loam (LAND 20-2005)				**50.0**	**50.0**	**160.0**	**50.0**	**50.0**	**1.0**
Background concentrations of HM in sandy loam			Total forms	**3.55**	**9.42**	**20.64**	**6.59**	**6.82**	**0.43**
(Lubytė ir kt., 2001)			Mobile forms	**0.23**	**1.4**	**1.7**	**0.71**	**0.49**	**0.13**
Background concentrations of HM in sod podsol sandy soil			Total forms	**13.0**	**15.0**	**22.0**	**14.0**	**18.0**	**0.2**
(Vokė) (Lubytė ir kt., 2001)			Mobile forms	**0.3**	**1.0**	**2.4**	**0.1**	**0.2**	**0.05**

* Eitminavičiūtė et al., 2005.

microarthropod complex develops with the eudominant oribatid *Tectocepheus velatus* (69.7%). The widespread *Oppiella nova* accounted for 6.4% in the landfill soil. It was more abundant only in the eighth and ninth years (Table 1). The distribution of microarthropod communities was related not only with the amount of organics but also with its pH. *Tectocepheus velatus* was tolerant to substratum alkalinity, whereas *Oppiela nova* in these soils was sparse (Эйтминавичюте, 2006, 2006a).

The desiccated sewage sludge of the Vilnius city is highly alkaline. When a landfill or a quarry is covered with this sludge, the soil reaction gradually changes from alkaline to neutral. In the sixth year the landfill soil was weakly alkaline, and in the ninth year it was almost neutral (Table 2). This may be the cause of the spread of *Oppiella nova* in the landfill soil.

Soil moisture plays an important role for microarthropods, *Collembola* in particular. Soil moisture was lowest in the sixth year of remediation (14.4%, 14.6%). In the last few decades, there was a tendency of soil temperature and soil moisture reduction (Bukantis et al., 2001). In 2003, even the abundance of the dominant *Collembola* species, *Isotoma notabilis*, and especially of *Mesophorura gr. krausbaueri* considerably reduced.

Rather high concentrations of heavy metals (Antanaitis, 2001; LAND 20-2005; 86/278/EEB) are allowed when landfills are remediated with sewage sludge. The Vilnius sewage sludge that was used for remediation of the Ne-

Table 4. **Microarthropod abundance (thou ind./m^2) and community structure in the soil of Nemenčinė landfill peripheries in the 5th–9th years of remediation with sewage sludge**

Year after the beginning of remediation	Year	Month	Microarthropod group												Σ		x̄
			Oribatida		*Acaridiae*		*Gamasina*		*Tarsonemina*		*Other mites*		*Collembola*				
			T.ind./m^2	%	T.ind./m^2	%	T.ind./m^2	%	T.ind./m^2	%	T.ind./m^2	%	T.ind./m^2	%	Month	Year	
5	2002	05	6.7	13.4	27.6	55.3	3.0	6.1	8.7	17.4	0	0	3.9	7.8	49.9	135.1	67.5
		09	10.3	12.1	8.5	10.0	2.2	2.6	55.6	65.2	0	0	8.6	10.1	85.2		
6	2003	05	21.7	53.2	0.1	0.2	2.3	5.6	12.0	29.4	2.5	6.1	2.2	5.4	40.8	67.3	33.6
		09	7.7	29.1	2.4	9.1	1.9	7.2	8.9	33.6	1.4	5.3	4.2	15.8	26.5		
7	2004	05	9.0	27.4	1.8	5.4	7.9	23.8	5.0	15.1	0	0	9.4	28.3	33.1	58.9	29.4
		09	5.8	22.5	0	0	9.3	36.0	5.9	22.7	0	0	4.8	18.6	25.8		
8	2005	05	8.1	8.1	1.0	0.3	4.7	4.7	52.7	53.1	6.2	6.2	27.4	27.6	100.1	161.2	80.6
		09	11.9	19.4	4.6	7.5	7.9	13.0	16.1	26.3	1.1	1.8	19.5	32.0	61.1		
9	2006	05	14.4	31.8	0.3	0.6	3.5	7.7	15.6	34.4	4.4	9.7	7.1	15.7	45.3	132.4	66.2
		09	19.9	22.8	0.8	0.9	8.8	10.1	46.6	53.5	2.9	3.3	8.1	9.3	87.1		
Σ			115.5	20.8	47.1	8.5	51.5	9.3	227.1	40.9	18.5	3.3	95.2	17.2	554.9		

menčinė landfill had considerably lower concentrations of these metals. In the first year of remediation, the concentration of these metals reduced negligibly: copper from 222.4 to 135.0, zinc from 619.0 to 612.0 and nickel from 91.8 to 87.3 mg/kg (Eitminavičiūtė et al., 2005). In the 5th–9th years, the concentrations of some metals were considerably smaller: the concentration of copper reduced from 222.4 to 99.8 mg/kg, zinc from 619.6 to 360.5, nickel from 91.8 to 50.6 and cadmium from 5.8 to 3.2 mg/kg. The concentrations of lead and chromium remained on the same level (Table 3). Yet the concentrations of heavy metals varied considerably from year to year. Presumably, the thin sludge layer (10–20 cm) only partly covered the landfill. Moreover, different kinds of wastes could increase the concentrations of some metals.

Analytical data showed that in the 5th–9th year of landfill soil remediation with sewage sludge, the concentration of copper ranged from 29.3 to 136.0 mg/kg, lead from <2 to 111.0, zinc from 97.3 to 1010.0, nickel from 11.7 to 74.7, chromium from 6.0 to 343.7, and cadmium from <0.1 to 8.4 mg/kg (Table 3). Only zinc and chromium concentrations exceeded the permissible values (LAND 20-2005). The mobile forms of heavy metals accounted for 25% (cadmium), 10.9% (zinc), 6.6% (lead), 2.3% (copper), 1.1% (chromium), and 0.7% (nickel) of the total of the determined concentrations (Lubytė ir kt., 2001; HN60-2004).

The obtained results showed that in the 5th–9th years of remediation with sewage sludge, the landfill soils were mostly polluted with zinc (average value 360.5 mg/kg) and chromium (106.0 mg/kg). In the 1st–2nd and 5th–9th years of remediation, the concentrations of heavy metals reduced: copper 1.3, lead 1.0, zinc 1.7, nickel 1.7 and cadmium 2.4 times. However, the concentrations of chromium and lead increased 2.8 and 1.0 times, respectively.

As a result of the activity of plant roots, microorganisms and zoocoenoses – intensive mineralization and humification of organics – some heavy metals are released and accumulate in plants. In autumn, when organic waste disintegrates, some heavy metals get back to the soil. With the increasing amount of humus, increasing portions of heavy metals get bound and thus less are washed out and absorbed by plants. In the 5th–9th years of remediation, the concentrations of zinc and chromium were highest. Plants contained 55.7 mg/kg of zinc. This is 1.7 times as much as in the grass of the city and 4.7 times as much as in perennial herbs growing in clean soil (Table 3). It should be noted that the concentration of zinc in the soil is reflected in its plant cover. Presumably this is related with the mobile forms of zinc which account for 11% of the total. The landfill plants also contain high concentrations of copper and nickel.

Analysis of heavy metal concentrations in the soil and their penetration into plants has showed that the metals whose highest concentrations accumulate in the soils have best possibilities to be absorbed by plants. As was mentioned, the highest concentrations in the landfill soils were characteristic of zinc and chromium.

Investigation of a natural meadow between the landfill and the pine forest showed that the total abundance of microarthropods in its soil ranged in different years from 29.4 to 80.6 thou ind./m^2 (Table 4). Their community included 20 *Oribatida*, 27 *Gamasina* and 22 *Collembola* species (a total of 69 species). They are typical species of low productivity sandy meadows. *Tarsonemina* (rather abundant in this soil) make an exception. Usually *Tarsonemina* abound in the drained meadows (Лазаускене, Севастьянов, 1972). The control site borders on a drained field of perennial grasses, a pine forest and a landfill on the other side of the ditch. The proximity of a drained meadow might have influenced the spread of *Tarsonemina*. In our investigation site, tarsonemic mites accounted for 40.9% of the total of microarthropods, *Oribatida* for 20.8%, *Gamasina* for 89.3%, *Acaridae* for 8.5% and *Collembola* for 17.1% of the total of microarthropods (Table 4).

The concentrations of heavy metals in the soil of the meadow in the outskirts were low and comparable with the concentrations typical of sandy loam soils. They did not exceed the highest permissible values for this type of soil (Table 3).

The grass in the vicinities of the landfill contained highest concentrations of zinc. In the 5th–9th years of remediation, its average concentration was 45.2 mg/kg. This is 1.4 times as much as in the city grass (Adomaitis,

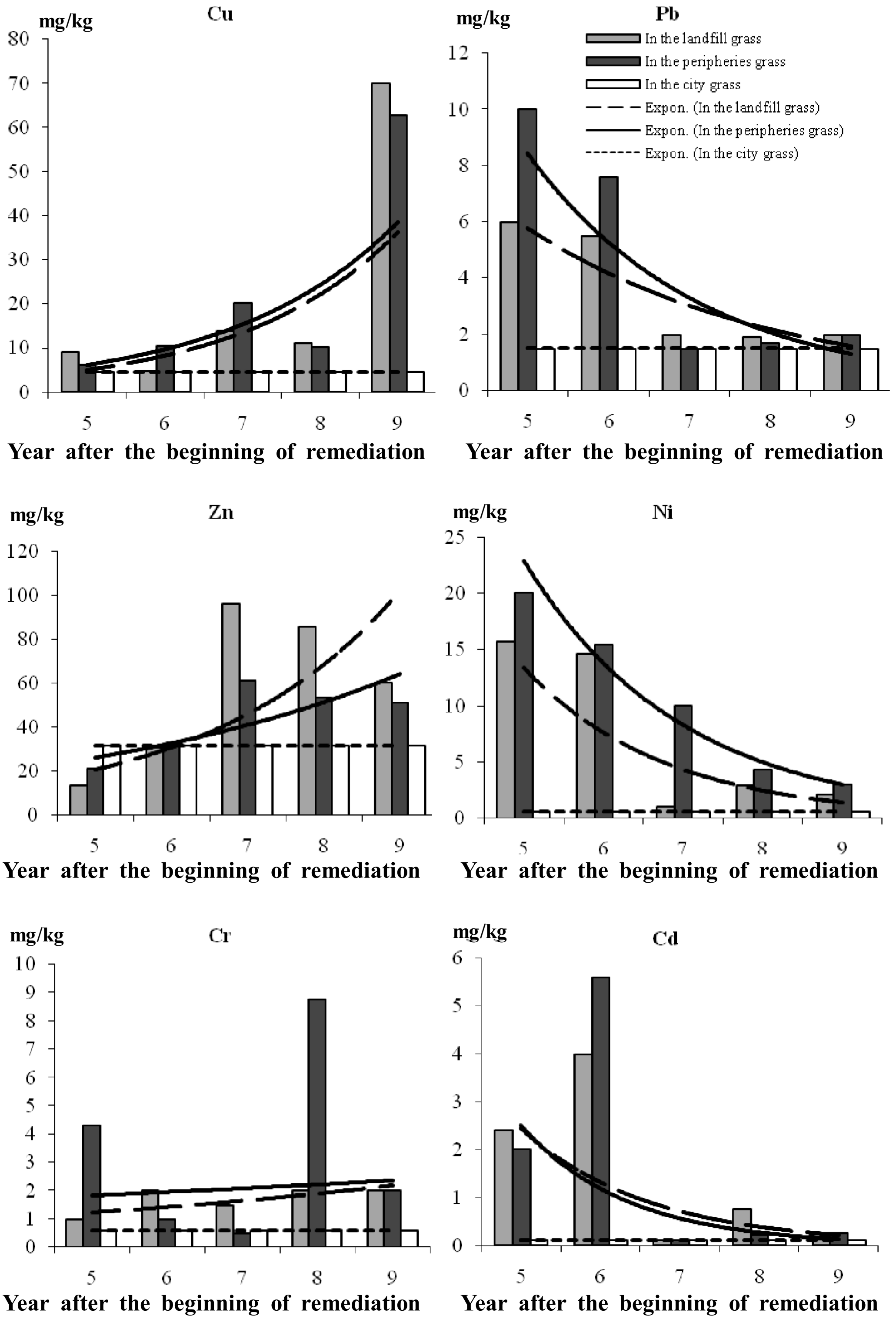


Fig. 3. Concentration of heavy metals (mg/kg) in the grass cover of Nemenčinė landfill remediated with sewage sludge and of its peripheries

Mažvila, 2001) and 3.8 times as much as in perennial grasses (Lubytė ir kt., 2001). The concentrations of copper and nickel in the grass covering the peripheral part of the landfill were also rather high (Fig. 3).

CONCLUSIONS

In the case of remediation of landfill soils with an organics-rich substratum such as sewage sludge, the process of soil formation is more intensive than in the case of remediation with organics-poor substratum. In the 5th–9th years of remediation, the content of humus reached 6.0%.

In the 5th–9th years after insertion of sewage sludge (450 t/ha), the concentrations of heavy metals reduced 1.0 to 2.4 times. Only the concentrations of lead and chromium slightly increased. Zinc was the main pollutant of landfill soil (360.5 mg/kg). This element was accumulated in greatest concentrations by the herbal plants of the landfill as well. The concentrations of heavy metals in the landfill soil did not inhibit the natural microarthropod successions reflecting the intensity of organics destruction. In the 5th–9th years of remediation, a certain equilibrium set in among the microarthropod groups. Three varieties were dominant: *Tectocepheus velatus, Isotoma notabilis* and *Mesophorura gr. armata*. A total of 55 microarthropod varieties were identified.

In the soil of the peripheral part of the landfill, the concentrations of heavy metals were comparable with the background values. The herbal plants (as in the landfill) accumulated greatest concentrations of zinc.

ACKNOWLEDGEMENTS

The authors thank Dr. B. Kadytė for the identification of *Gamasina* and R. Gulbinaitė for assistance in preparing the paper.

Received 2 September 2006
Accepted 10 February 2007

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SĄVARTYNŲ DIRVOŽEMIŲ REKULTIVACIJA NUOTEKŲ DUMBLU

2. MIKROARTROPODŲ KOMPLEKSO STRUKTŪRA DIRVOŽEMIO FORMAVIMOSI PROCESE

Santrauka

Palaidotų ir sunaikintų žemių rekultivacija yra viena aktualiausių problemų, išsaugant sausumos ekosistemas. Sąvartynų rekultivacijai panaudojant miestų nuotekų dumblą sprendžiama nuotekų dumblo utilizacijos ir sąvartynų rekultivacijos problema, o dirvožemio formavimosi procesų intensyvumas tiesiogiai priklauso nuo įterpiamų organinių medžiagų kiekio ir pedobiontų veiklos.

Atlikti tyrimai rodo, kad per 9 metus rekultivuojant sąvartynus nuotekų dumblu besiformuojantis dirvožemis turi iki 6,0% humuso, daugiausia yra užterštas cinku (360,5 mg/kg) ir chromu (106,0 mg/kg). Daugelio sunkiųjų metalų koncentracijos per 9 metus sumažėjo iki 2,4 karto. Rekultivuojant sąvartynus nuotekų dumblu esamos sunkiųjų metalų koncentracijos nestabdo dirvožemyje vykstančių mikroartropodų sukcesijų. Mikroartropodų bendrijoje tarp grupių nusistovi tam tikra pusiausvyra, nors dirvožemyje vyrauja euribiontinės rūšys – *Tectocepheus velatus*, *Isotoma notabilis, Mesophorura gr. armata*. Sąvartyno dirvožemis ir žolės daugiausia užterštos cinku. Cinką daugiausia akumuliuoja ir žolės sąvartyno prieigose.

Raktažodžiai: sąvartynas, sąvartyno prieigos, sunkieji metalai, mikroartropodai, nuotekų dumblas