Vegetation Pattern and Heavy Metal Accumulation at a Mine Tailing at Gyöngyösoroszi, Hungary

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Z. Naturforsch. **60 c,** 362–367 (2005)

Vegetation at an abandoned heavy metal bearing mine tailing may have multifunctional roles such as modification of water balance, erosion control and landscape rehabilitation. Research on the vegetation of mine tailings can provide useful information on tolerance, accumulation and translocation properties of species potentially applicable at moderately contaminated sites. Analyses of the relationship between heavy metal content (Pb, Zn and Cu) and vegetation in a mine tailing were carried out. These analyses included: (1) spatial analysis of relationship among heavy metal distribution, pH and vegetation patterns, and (2) analysis of heavy metal accumulation and translocation in some plant species. Presence of vegetation was found to be significantly dependent on pH value, which confirms that phytotoxicity is a function of element concentration in solution, which is primarily controlled by pH value in mine tailings. Among the most abundant plant species, dewberry (*Rubus caesius*), vipersbugloss (*Echium vulgare*), scarlet pimpernel (*Anagallis arvensis*) and narrowleaf plantain (*Plantago lanceolata*) accumulate significant amounts of Pb, Cu and Zn, while in the case of annual bluegrass (*Poa annua*) only Pb can be measured in elevated contents. Considering the translocation features, scarlet pimpernel, narrowleaf plantain, and dewberry accumulate heavy metals primarily in their roots, while heavy metal concentration in vipersbugloss and annual bluegrass is higher in the shoots.

Key words: Heavy Metal, Mine Tailing, Vegetation

Introduction

Risk assessment and evaluation of recultivation technologies of sites where contaminants originate from mining activity and mining waste disposal are considered specific areas (Scokart *et al.*, 1983). For recultivation of mine tailings, taking both economical and technological feasibilities into consideration, phytoremediation has been widely studied (Cunningham *et al.*, 1995; Schnoor and Dee, 1997; Prasad and Freitas, 1999; Simon *et al.*, 2002). Phytoremediation technology seems to be applicable, since these sites have relatively low environmental impact. That is, contaminants do not show high dispersion resulting in hazard of surface and subsurface water pollution as well as human health risk through land use. However, revegetation of mine tailings may be difficult due to high salt concentration, heavy metals, insufficiently available nutrients, and poor water management (Johnson *et al.*, 1977; Vangronsveld *et al.*, 1994, 1996).

The role of vegetation is significant in changing water balance, erosion control, and landscape (Kamnev and van der Lelie, 2000). Phytoremediation of mine tailings is an efficient method for erosion and runoff control as well as to reduce heavy metal transport through infiltration (Palmer, 1992; Vangronsveld *et al.*, 1995; Zhu *et al.*, 1999). Research on natural vegetation of mining areas having high metal content provides information relevant to risk assessment and remediation planning, and results are also important from an ecological point of view (Thompson and Proctor, 1983; Leita and De Nobili, 1989; Wenzel and Jockwer, 1999; Fernandez-Turiel *et al.*, 2001; Galicz *et al.*, 2002; Hayes and Traina, 1998).

Primary vegetation found in mine tailings is generally sparse, with few species. However, the presence of species tolerating extreme conditions results in increasing organic content and improves soil quality (Sieghardt, 1989). Considering the colonisation by higher plants, Connell and Slatyer (1977) suggested three succession models based on facilitation, tolerance and inhibition. According to Ernst (1989), the first one can be adapted to mine tailings.

Vegetation pattern and species distribution of a mine tailing correlate more strongly with pH value and cation exchange capacity than total heavy metal concentration (Wickland, 1989). However, heavy metals have a significant role in that vegetation and succession of contaminated sites differs from that of uncontaminated areas (Brümmer *et al*., 1986).

This study summarizes the results of the spatial analysis of relationship among heavy metal distribution, pH value and vegetation patterns based on field measurements at an abandoned mine tailing, and that of the analysis of heavy metal accumulation and translocation in some local plant species.

Materials and Methods

The relationship between vegetation pattern, heavy metal distribution and pH value was analysed at the Gyöngyösoroszi mining site in North Hungary, where Pb and Zn were mined from 1952 to 1986. At the site a qualitative environmental impact assessment was carried out by Horváth and Gruiz (1996). Ódor *et al*. (1998) conducted geological and geochemical investigations and a preliminary analysis of the natural vegetation was carried out by Galicz *et al*. (2002).

The factors that potentially determine the presence/absence of vegetation were analysed at a 5 m × 16 m area selected on the basis of previous studies, where plant species identification and mining waste sampling were carried out systematically in a 50 cm × 50 cm grid. Coenological survey was carried out in September 2001–2003, and relationships between heavy metal content and vegetation were analysed. The heavy metal accumulation and translocation features were characterised for 5-5 individuals of the most abundant plant species: *Rubus ceasius*, *Echium vulgare*, *Poa annua*, *Plantago lanceolata* and *Anagallis arvensis*. The element contents of plant roots and shoots for dry material were measured with ICP-OES after wet HNO_3/H_2O_2 digestion. Heavy metal contents (Zn, Pb and Cu) were measured with a field portable XRF spectrometer (NITON XL700) calibrated with respect to the matrix effect by comparing data to ICP results and normalizing to water content. Measurements were carried out for ground and air-dried samples according to the US EPA 6200 method worked out for the FPXRF technique. The pH value of each sample was determined potentiometrically.

Geo-statistical and spatial pattern analyses were carried out using the software Idrisi 32 and the Mann-Whitney-Wilcoxon test was used to evaluate the dependence of presence/absence of vegetation on heavy metal concentration and pH value.

Results and Conclusions

Vegetation of the mine tailing

Most plant species identified at the mine tailing favour moderately dry climate and the most abundant species prefer neutral or moderately alkaline soils. Plants found at the study area in September 2001–2003 are listed in Table I. Considering the natural protection category, the dominant species indicate degradation, they are weeds and resistant ones, while pioneers and accompanying species are less abundant. The small number of association-forming species indicates that stable associations have not yet appeared. Neither the R nor the W spectrum show trends (data not shown) indicating that soil characteristics and microclimate did not change significantly during 3 years.

Spatial relations between vegetation, heavy metal concentration and pH value

Spatial pattern analysis of vegetation, heavy metal content and pH value may reveal the factors that determine plant growth at mining areas. There is no significant correlation between total heavy metal content and pH value in the case of Pb, while for Zn and Cu the Spearman coefficients are 0.546 ($P < 0.01$) and 0.374 ($P < 0.01$), respectively.

The Mann-Whitney-Wilcoxon probe shows that the spatial pattern of the vegetation does not vary with total heavy metal concentration. Probabilities of validity of H0 (P) for Cu, Zn, Pb and pH are 0.749, 0.263, 0.012, and 0.000, respectively. Thus, median values for total heavy metal concentrations measured at areas having vegetation cover and for those where vegetation is absent do not differ significantly. However, the presence of vegetation is significantly dependent on the pH value of the soil.

Linear multistep regression analyses also confirm that the pH value is the determining factor with respect to vegetation cover and show that the correlation is significant at $P < 0.01$ (Table II).

Considering the number of species, statistical analyses show that the total heavy metal contents are also not determinative, but the pH value has a significant effect ($P < 0.01$) (Table II). At the same time, correlation coefficients are rather low and indicate a poor relationship. Phytotoxicity is a func-

Table I. Identified species at a mine tailing at Gyöngyösoroszi, Hungary between 2001 and 2003.

Species	T	W	R	TVK	2001	2002	2003
Agropyron repens	5	3	0	GY			X
Anagallis arvensis	6a	3	4	GY	X	X	
Arrheanathelum elatius	5a	5	4	TZ		X	
Artemisia absinthium	6	3	4	GY		X	
Artemisia vulgaris	5	4	0	GY		X	X
Betula pendula	3	4	0	E		X	X
Carduus acanthoides	6a	3	0	GY		X	
Carex hirta	5a	7	0	GY			X
Centaurea jacea	5a	6	0	TZ		X	X
Cerastium semidecandrum	6a	3	0	TP		X	X
Cirsium arvense	5	4	0	GY	X	X	X
Conium maculatum	5a	5	3	GY	X	X	
Convolvulus arvensis	0	3	4	GY		X	X
Dactylis glomerata	5a	6	4	TZ			X
Daucus carota	5a	2	5	TZ			X
Echium vulgare	6a	3	0	TP	X	X	X
Euphorbia cyparissias	5k	3	4	GY		X	X
Euphorbia seguieriana	6k	1	4	K	X		
Festuca heterophylla	5a	4	3	K	X	X	X
Festuca pratensis	5	7	4	E	X	X	X
Fragaria vesca	5	5	3	K	X		
Lotus corniculatus	5a	4	0	TZ			X
Lupinus albus					X		
Medicago falcata	6k	3	4	TZ			X
Medicago minima	7	2	4	TP		X	X
Melandrium album	5	4	0	G	X	X	X
Plantago altissima	5a	7	4	TZ		X	
Plantago lanceolata	5a	4	0	TZ(K)	X	X	X
Plantago major	5a	7	0	GY		X	X
Plantago media	5	5	0	TZ	X	X	
Poa annua	0	8	0	GY	X	X	X
Poa nemoralis	5	4	3	TZ			X
Poa pratensis	5	6	0	K	X	X	X
Polygonum aviculare	0	4	3	GY		X	X
Polygonum lapatipholium	0	9	3	GY	X		X
Potentilla reptans	0	6	3	TZ	X	X	X
Prunus spinosa	5a	3	3	TZ	X	X	X
Pulmonaria officinalis	5a	6	3	K		X	
Robinia pseudo-acacia	5	3	4	GY		X	X
Rubus ceasius	5	8	4	TZ	X	X	X
Silene vulgaris	5	3	4	K		X	X
Stellaria graminea	5	4	3	TZ		X	X
Stellaria media	0	5	0	GY	X		
Taraxacum officinale	0	5	0	GY	X	X	X
Trifolium pratense	5	6	3	TZ		X	X
Trifolium repens						X	

T, heat management – climate (0: uncharacteristic, 3: taiga, 5: deciduous forest, 6: submediterranean deciduous forest, 7: mediterranean atlantic evergreen forest, a: atlantic, k: continental); W, water management (1: very dry, 2: dry, 3: moderately dry, 4: moderately fresh, 5: fresh, 6: moderately wet, 7: wet, 8: moderately watery, 9: watery); R, soil reaction – pH (0: uncharacteristic, 3: nearly neutral, 4: moderately basic, calcareous, 5: calcareous, basic); TVK, natural protection category (TZ: resistant, K: accompanying, GY: weed, G: crop, E: association composing, TP: pioneer).

tion of element concentration in solution, which is primarily controlled by pH. However, the pH value also determines several physiologically important and essential soil parameters in addition to the potentially bio-available metal concentrations.

Heavy metal uptake at mine tailings

Heavy metal contents measured in plant shoots and roots were compared to contents characteristic in the environment of the rhizosphere. Heavy

Table II: Results of regression analyses for vegetation pattern–heavy metal distribution–pH relationship and number of species–heavy metal distribution–pH relationship.

	n	Value	Standard error	T	P	r
y(presence of vegetation) = *a* [Pb] + *b* [Zn] + *c* [Cu] + d pH + *e*						
Model 1	312					0.431
a		–0.000015	0.000008	–1.80	0.073	
b		–0.000005	0.000003	–1.80	0.074	
c		–0.0000007	0.000013	–0.05	0.956	
d		–0.156	0.023	6.84	0.000	
e		–0.083	0.134	–0.62	0.538	
Model 2	316					0.439
d		0.13	0.02	6.53	0.000	
e		–0.086	0.12	–0.72	0.474	
y(number of species) = *a* [Pb] + *b* [Zn] + *c* [Cu] + *d* pH + *e*						
Model 1	312					0.130
a		–0.00001	0.00002	–0.47	0.637	
b		–0.00002	0.000008	–2.59	0.010	
c		–0.000019	0.000036	–0.53	0.596	
d		0.399	0.06	6.54	0.000	
e		–0.68	0.36	–1.90	0.058	
Model 2	316					0.085
d		0.288	0.053	5.39	0.000	
e		–0.412	0.321	–1.28	0.201	

Table III: Accumulated heavy metal contents for the examined species ($N = 5$) (mg kg^{-1} dry material).

Species	Cu	Zn	Pb
Anagallis arvensis			
Medium	1580 ± 155	5968 ± 160	4278 ± 120
Shoot	208 ± 107	2722 ± 156	485 ± 140
Root	1195 ± 961	7951 ± 2846	3206 ± 118
Echium vulgare			
Medium	607 ± 130	18496 ± 305	6099 ± 185
Shoot	205 ± 45	1224 ± 396	348 ± 195
Root	130 ± 108	1611 ± 582	363 ± 300
Plantago lanceolata			
Medium	1828 ± 165	16192 ± 280	7699 ± 200
Shoot	144 ± 189	738 ± 542	218 ± 210
Root	152 ± 139	1179 ± 228	285 ± 91
Rubus ceasius			
Medium	2080 ± 170	13888 ± 270	4329 ± 110
Shoot	42 ± 28	860 ± 354	109 ± 90
Root	107 ± 33	1340 ± 362	263 ± 126
Poa annua			
medium	1369 ± 150	7724 ± 180	4057 ± 125
Shoot	9.6 ± 8.4	104 ± 37	273 ± 172
Root	27 ± 15	138 ± 61	497 ± 613

metal tolerance in plants varies with each species and heavy metal. Based on their accumulation features, our results show that the most abundant plants are highly metal tolerant, and accumulate heavy metals in considerable amounts (Table III). This observation is important when a phytoextraction technology is considered. The most abundant species found at the mining area have high Pb, Zn and Cu accumulating ability, with the exception of annual bluegrass, which accumulates only Pb in large amounts and excludes Zn and Cu. These results are in agreement with those of Djingova *et al.* (1993). Scarlet pimpernel, narrowleaf plantain and dewberry were found to accumulate heavy metals primarily in their roots, while vipersbugloss accumulates Pb and Cu in the shoots.

Acknowledgements

Research was carried out as a part of the project BIO-02453/2000 financed by the Ministry of Education, Hungary. The authors thank the staff at the Department of Water and Environmental Management, University of Debrecen, Hungary for their help in the research.

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Satz und Druck: AZ Druck und Datentechnik GmbH, Kempten