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Mariola WRÓBEL[1], Justyna CHUDECKA[2],
Tomasz TOMASZEWICZ[2] and Małgorzata GAŁCZYŃSKA[3]

CONTENTS OF HEAVY METALS IN ROADSIDE SOILS AND SPATIAL DISTRIBUTION OF METALLOPHYTE PLANT SPECIES ON THE ROADSIDES OF SZCZECIN LOWLAND

ZAWARTOŚĆ METALI CIĘŻKICH W GLEBACH PRZYDROŻNYCH A PRZESTRZENNE ROZMIESZCZENIE GATUNKÓW METALOFITÓW NA POBOCZACH DRÓG NIZINY SZCZECIŃSKIEJ

Abstract: Research on soil pollution with heavy metals and roadside metallophyte plant species spatial distribution along public roads within forest and agricultural areas in Szczecin Lowland was carried out. The roadside zones of about 8 m total width were surveyed. The total content of Mn, Pb and Cu in field and forest roadside soil samples decreased in roadside zones as moving away from the road. However, in the zone of 2 m width the field roadside soil showed the accumulation higher level of the analysed heavy metals as compared with that of forest one, ie by about 25 % more of Pb and Mn and about 60 % more of Cu. Differences in the content of heavy metals in roadside soils depended on a zone distance from the road, the soil granulation and pH reaction. Analysis of spatial and quantitative distribution of metallophyte species against the background of zonal roadside structure confirmed obtained results concerning the presence of heavy metals in roadside soil samples.

Keywords: roadside flora, metallophyte species, heavy metals, polluted soils

Roadside flora as well as the soil and air in the vicinity of roads undergo contamination by oil derivatives and carbon, nitrogen and sulphur oxides as well as by toxic heavy metal compounds and elements contained in motor vehicle exhausts. Automobile exhaust emission is accompanied by deposition of dust on the roadway and roadside. This dust is produced as a result of wearing off the break lining, tyres, road

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[1] Department of Botany and Nature Protection, West Pomeranian Technological University, ul. J. Słowackiego 17, 71–434 Szczecin, email: mariola.wrobel@zut.edu.pl

[2] Department of Soil Erosion and Soil Reclamation, West Pomeranian Technological University, ul. Pawła VI 1, 71–441 Szczecin, email: erozja@zut.edu.pl

[3] Department of Chemistry, West Pomeranian Technological University, ul. J. Słowackiego 17, 71–434 Szczecin, email: malgorzata.galczynska@zut.edu.pl

surface and lacquered car body metal elements as well as due to carrying various cargos [1, 2]. Road dusts and motor vehicle exhausts contain first of all Zn, Cu, Pb, Cd and Mn but the roadside soil is contaminated the most by heavy metals. These chemical elements get into soil with dry deposition and rainwater, with their highest concentration being observed in the soil top, 0.2 m deep humus layer directly adjacent to the roadway as well as in the roadside zone of several meters width. The observable decrease of their content is found only at the distance of 50–100 m from the road [3–5].

Excessive amounts of heavy metals in soil lead to plant external damages, metabolic conversion disturbances and increased accumulation in plant organs. The largest amounts of these chemical elements are found in plant roots and overground vegetative parts, while the least ones in generative organs. The increased content of heavy metals in plant overground organs is a result of direct effect of dusts and automobile exhausts. On the other hand, heavy metals pervade the plant roots from the soil contaminated by these chemical elements. The overabundance of heavy metal ions induces a series of biochemical and physiological changes in plant cell, which are defined as the syndrome of features being characteristic for heavy metal-induced stress [6–9].

Material and methods

The aim of undertaken studies was evaluation of the road shoulder soil pollution with heavy metals and its influence on the presence of metallophyte species in roadside flora of forest and field roads. Field observations were carried out in 2006–2007 at 8 permanent study points located along forest and field public roads with hardened surface outside the built-up area (Szczecin Lowland). The field roads were running through the pastures, grasslands, arable and fallow lands whereas the forest ones were situated within timber forests of the Goleniow Primeval Forest. The location of each permanent study point was marked with GPS respectively for forest roads (L1: 53^{o}34′26″N, 014^{o}47′09″E; Λ2: 53^{o}33′03″N, 014^{o}36′32″E; L3: 53^{o}27′08″N, 014^{o}52′12″E; L4: 53^{o}27′08″N, 014^{o}52′12″E) and the field ones (P1: 53^{o}18′17″N, 014^{o}48′0″E; P2: 53^{o}07′26″N, 014^{o}47′14″E; P3: 53^{o}20′28″N, 014^{o}47′14″E; P4: 53^{o}20′07″N, 014^{o}51′41″E) [10].

In all eight permanent study points were delimited 3 parallel transects crossing the road shoulder and including succeeding roadside zones: A – road shoulder edge (0–0.3 m width), B – proper road shoulder (0.3–2 m), C – ditch (2–5 m) and D – slope (5–8 m). In the each zone of the transect a plot (1 m^2) was delimited where all occuring plant species and their participation in vegetation cover of the plot were noticed. The nomenclature of identified vascular plants was given after Rothmaler [11] and Mirek [12]. The plant species resistant to increased heavy metal content in the soil and defined as metallophyte species were distinguished basing on the Zarzycki's ecological index numbers [13].

Out of each of the eight permanent study points, cumulative soil samples from four separated roadside zones were collected. In total, 32 soil samples from the top humus layer of soil (0–0.1 m) were obtained. For the soil samples composition and reaction measured in KCl with a concentration of 1 mol · dm^{-3} (pH in KCl) were determined.

The total content of lead, copper and manganese was assayed with the AAS method, after previous mineralisation of soil material in chloric(VII) (perchloric) and nitric(V) acid mixture (1:1) in a ratio of 1:10 (soil : acid).

Results and discussion

Basing of the results of floristic observations carried out in designated study points in the Szczecin Lowland, the presence of plant species tolerating the increased content of heavy metals in soil was found in the roadside flora. From among 143 noticed plant species up to 21 metallophyte species were recognized (14.6 %). These species belonged to 10 families (with the most numerously represented was *Poaceae* family) and participated in floristic composition of plant communities growing up on roadsides (Table 1).

Table 1

Spatial distribution of roadside metallophyte plant species in following zones of forest and field roadsides in Szczecin Lowland

Family	Metallophyte plant species	Field roadsides zones				Forest roadsides zones			
		A	B	C	D	A	B	C	D
Equisetaceae	*Equisetum arvense* L.	+	+	+	+	–	+	–	–
Chenopodiaceae	*Atriplex patula* L.	–	–	+	–	–	–	–	–
Caryophyllaceae	*Cerastium arvense* L.	–	–	–	–	–	–	+	–
	Cerastium semidecandrum L.	+	+	–	–	+	+	–	–
Rosaceae	*Fragaria vesca* L.	–	–	–	–	–	–	–	+
	Rubus caesius L.	–	+	+	+	–	–	+	–
	Rubus idaeus L.	–	–	–	–	–	–	–	+
Fabaceae	*Lotus corniculatus* L.	–	+	+	+	–	–	–	–
Convolvulaceae	*Convolvulus arvensis* L.	+	+	+	+	+	+	–	–
Campanulaceae	*Campanula rotundifolia* L.	–	–	+	–	–	–	–	–
Asteraceae	*Bellis perennis* L.	+	+	–	–	–	–	–	–
	Cichorium intybus L.	+	+	–	–	+	–	–	–
	Leontodon autumnalis L.	+	+	–	–	+	+	–	–
Poaceae	*Arrhenatherum elatius* (L.) P. B. ex J. et Presl	+	+	+	+	+	+	–	–
	Calamagrostis epigejos (L.) Roth	+	+	+	+	–	+	+	+
	Festuca ovina L.	–	–	–	–	–	+	+	–
	Festuca pratensis Hudson	+	+	+	–	–	–	–	–
	Festuca rubra L.	–	–	–	–	–	+	–	–
	Lolium perenne L.	+	+	–	–	+	+	–	–
Cyperaceae	*Carex arenaria* L.	–	+	+	–	–	+	+	+
	Carex hirta L.	+	+	–	–	+	+	–	–
Total	21	11	14	10	6	7	11	5	4

A – road shoulder edge; B – proper road shoulder; C – ditch; D – slope

The only species *Leontodon autumnalis*, described in literature as requiring the increased content of heavy metals in soil, grew up in masses in the proper roadside zone being contaminated the most by traffic pollutants coming from automobile exhaust emissions [13].

Spatial analysis of the distribution of distinguished metallophyte species against the background of zonal roadside structure showed significant floristic differences between the roads coming through forest lands and those under arable cultivation. They result not only from different character of vegetation which occurs in the road surroundings but first of all from different soil conditions and differences in the content of heavy metals in the roadside soil of analysed road types.

In Table 2 are presented the properties of soils sampled in the study points, which affect the availability of heavy metals for plants, ie soil reaction and content of granulometric fraction size ∅ < 0.02 mm [14]. Soil samples from the field roadsides, with content of granulometric fraction size ∅ < 0.02 mm from 7 to 16 %, were included into very light and light soils. Soil samples from the forest roadsides were more uniform in respect of size composition, they all belong to very light soils (with content of the granulometric fraction size ∅ < 0.02 mm from 2 to 7 %). Analysis of the reaction (pH_{KCl}) of soil coming from the forest roadsides showed a large differentiation of that trait. The top layer of soil (0–0.1 m), within the A and B roadside zones (to 2 m width), had a neutral reaction that changed to strongly acidic one in further roadside zones and was submitted to the acidifying effect of forest communities (fresh coniferous forest), through which the road was passing. The field roadside soils were generally characterised by a neutral reaction, although an increasing trend in the pH value (to alkaline one) was visible in the A roadside zone (0–0.3 m width). It results from the use of road surface deicing agents in winter (mainly sodium and calcium chlorides) which partly accumulate in the roadside soil [10].

When evaluating the total content of Mn, Pb and Cu in field and forest roadside soil samples (Table 2), a clear trend was observed to decreasing their quantities as moving away from the road. It was more clearly defined in relation to lead and copper than manganese. According to the evaluation criteria for the total content of heavy metal ions proposed by Kabata-Pendias [15], and presented in the table 2, the exceedance of natural lead and copper concentration to the level defined as the "raised" one (Ist degree), takes place within the two-meter zone of these soils, directly adjacent to the road (A and B roadside zones). Only in one case the copper concentration was defined as medium-contaminated soil (IIIrd degree).

Mean lead quantity in A and B zone (0–2 m total width) of field roadside soil amounts to 41.4 $mg \cdot kg^{-1}$ soil, while for that of forest roadside soil it is 31.1 $mg \cdot kg^{-1}$ soil; in case of Cu, respective mean values for field roadside soil and forest roadside one are 32.3 and 12.0 $mg \cdot kg^{-1}$ soil, whereas for Mn the mean quantity in field roadside soil is 316.0 and in forest roadside one is 237.3 $mg \cdot kg^{-1}$ soil. Thus, the field roadside soil within the A and B roadside zones shows a higher level of accumulation of the analysed heavy metals in relation to that of forest roadside soil, ie by about a quarter times higher with respect to lead and manganese and by about two and a half times higher in the case of copper.

Table 2

Selected parameters and total content of Mn, Pb and Cu in top soil layer (0–0.1 m) from field and forest roadsides with degree of their contamination with Pb and Cu (according to Kabata-Pendias [15])

Study point/ roadside zone		Granulometric fraction ∅ < 0.02 mm [%]	pH_{KCl}	Mn	Pb	Cu	Pb	Cu
				[mg · kg^{-1} soil]			evaluation acc. to Kabata-Pendias [15]	
Field roadsides								
P1	A	8	7.51	352.8	32.1	21.1	I	I
	B	8	7.26	301.3	26.3	18.6	I	I
	C	11	6.95	238.4	19.0	9.8	0	0
	D	13	7.02	237.6	11.5	7.5	0	0
P2	A	10	7.15	367.9	96.6	101.4	I	III
	B	11	7.23	267.2	34.9	41.4	0	I
	C	13	6.93	342.7	5.6	6.6	0	0
	D	14	6.70	216.2	8.0	12.7	0	0
P3	A	9	7.13	400.7	44.0	29.8	I	I
	B	7	7.09	342.6	29.2	11.0	I	I
	C	8	6.80	304.0	13.9	4.9	0	0
	D	7	6.24	262.2	10.5	4.4	0	0
P4	A	8	7.26	405.5	44.1	24.5	I	I
	B	13	6.98	338.7	24.0	10.6	I	I
	C	16	6.72	340.7	12.7	7.8	0	0
	D	14	6.38	255.1	9.6	7.0	0	0
Forest roadsides								
L1	A	6	7.15	336.4	31.0	13.3	I	I
	B	5	6.80	208.7	21.3	7.6	I	0
	C	7	6.12	183.0	20.3	6.0	I	0
	D	4	5.45	111.5	15.6	2.7	0	0
L2	A	3	7.06	274.4	23.0	14.6	I	I
	B	6	6.89	286.4	36.2	19.6	I	I
	C	7	6.11	181.2	17.9	4.0	0	0
	D	6	5.89	172.1	15.8	3.5	0	0
L3	A	5	7.00	299.7	37.0	17.5	I	I
	B	3	6.67	245.0	39.2	8.2	I	0
	C	2	4.98	124.8	18.4	2.7	0	0
	D	4	4.67	132.7	11.0	1.7	0	0
L4	A	5	6.80	212.5	42.5	13.3	I	I
	B	3	5.56	62.5	18.0	1.8	0	0
	C	2	4.87	74.7	12.7	1.8	0	0
	D	3	4.70	46.0	12.6	2.1	0	0

P1– P4 permanent study points along field roads; L1–L4 permanent study points along forest roads; A – road shoulder edge; B – proper road shoulder; C – ditch; C – slope; 0 – natural content; I – increased content; III – medium-contaminated soil.

When assuming that the traffic volume on the compared road types is similar, the differences in the content of heavy metals in the roadside soil have to be a result of their different size composition and reaction.

Loose roadside vegetation cover on forest roadsides favours deposition of traffic pollutants directly on the soil surface. However, due to very acidic reaction and larger permeability (when compared with the soil from field roadsides), heavy metal chemical elements migrate faster in the soil profile and are only partly assimilable by plants [16, 17].

Compact roadside vegetation cover on field roadsides partly stops deposition of motor vehicle exhausts and dusts on plants and decreases their deposition on the

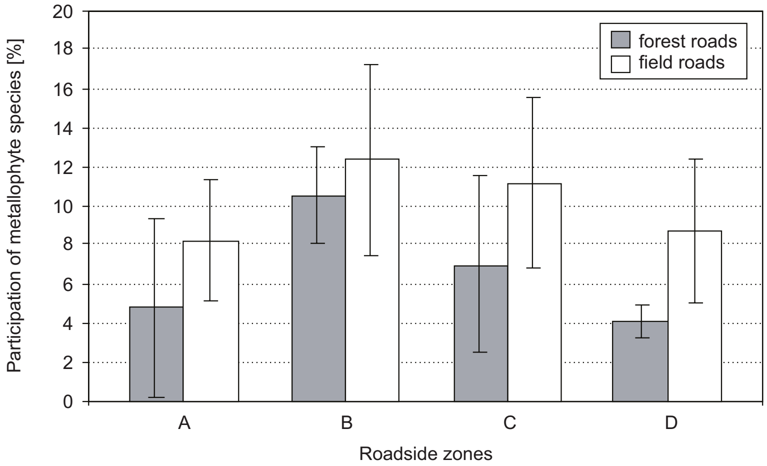

Fig. 1. Participation of metallophyte species in total number of species observed in following zones of forest and field roadsides: A – road shoulder edge; B – proper road shoulder; C – ditch; D – slope

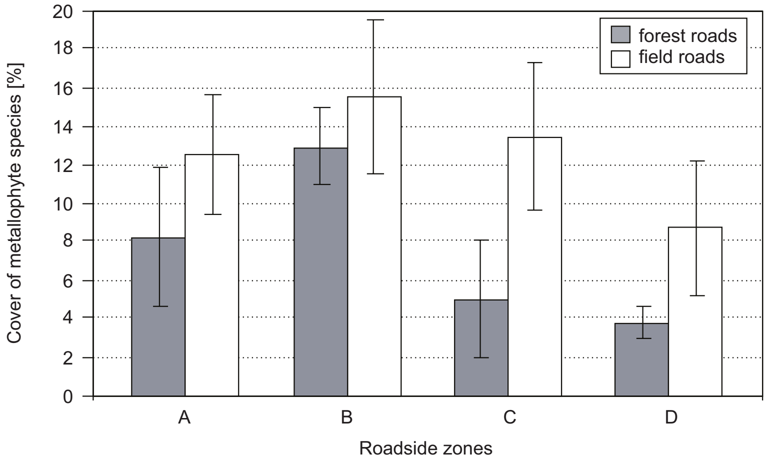

Fig. 2. Participation of metallophyte species in vegetation cover observed in following zones of forest and field roadsides: A – road shoulder edge; B – proper road shoulder; C – ditch; D – slope

roadside soil. However, a definitely neutral reaction and smaller permeability of soil from field roadsides affects the retention of examined heavy metal chemical elements in the top layer of soil [14]. The result of this is both a larger number of the metallophyte species found and their larger participation in vegetation cover on field roadsides (Fig. 1, Fig. 2).

Conclusions

1. The content of heavy metals in the forest anf field roadside soil is a result of their different granular composition and reaction.
2. Both the forest and field roadside soil pollution with examined heavy metals was increased in road shoulder edge and proper road shoulder zones. In following roadside zones (ditch and slope) the content of Mn, Pb and Cu was found at natural level.
3. The largest number of metallophyte species was observed in road shoulder edge and proper road shoulder zones both forest and field roads. In case of field roadsides found metallophyte species had larger participation in vegetation cover of these zones.

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ZAWARTOŚĆ METALI CIĘŻKICH W GLEBACH PRZYDROŻNYCH A PRZESTRZENNE ROZMIESZCZENIE GATUNKÓW METALOFITÓW NA POBOCZACH DRÓG NIZINY SZCZECIŃSKIEJ

Katedra Botaniki i Ochrony Przyrody, Zachodniopomorski Uniwersytet Technologiczny

Abstrakt: Przedstawiono wyniki badań dotyczące zawartości wybranych metali ciężkich w glebach poboczy dróg i przestrzennego rozmieszczenia metalofitów – gatunków roślin tolerujących obecność tych pierwiastków w glebie. Badaniami objęto strefy pobocza o łącznej szerokości 8 m, wzdłuż dróg o nawierzchni utwardzonej przebiegających przez kompleksy leśne i tereny rolnicze na Nizinie Szczecińskiej. Ogólna zawartość Mn, Pb i Cu w próbkach przydrożnych gleb śródpolnych i śródleśnych zmniejszała się w kolejnych strefach pobocza, przy czym gleby śródpolne w strefie 2 metrów od drogi kumulowały o 25 % więcej Pb i Mn oraz o ok. 60 % więcej Cu. Różnice w zawartości badanych metali ciężkich w próbkach wynikały z położenia strefy względem drogi oraz zróżnicowanego uziarnienia i odczynu gleb przydrożnych. Potwierdziła to analiza przestrzennego i ilościowego rozmieszczenia gatunków metalofitów na tle strefowej budowy poboczy dróg na badanym terenie.

Słowa kluczowe: flora przydrożna, metalofity, metale ciężkie, gleby zanieczyszczone