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Function of roadside vegetation in protection of soil from automotive environment pollutants: a case study of zinc

Rola zieleni przydrożnej w ochronie gleb przed motoryzacyjnymi zanieczyszczeniami środowiska na przykładzie cynku

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Abstract

Road dust is one of the most toxic substances found in the environment. Numerous reports found in the literature confirm that proper plantations of various plants can protect areas surrounding communication routes. This way, spreading of different pollutants, including heavy metals, is limited. Determination of total and available zinc content in soil of roadside and soil of a parcel directly neighbouring the roadside on which Virginia mallow was cultivated, plantations of which were supposed to fulfil a function of a biological road screen, was the aim of the investigation. Content of zinc in particular parts of Virginia mallow was also determined. Obtained results of the investigation indicate that content of zinc in soil, on which Virginia fanpetals was cultivated, was similar to its content in soil of roadside directly adjacent to the road. In a course of two years of conducting the investigation, no decrease of the element was observed in the soil of both experimental plots. Moreover, the highest content of zinc was noted in leaves, which are the part of the plant most exposed to automotive pollution, lower in roots and the lowest in stems of investigated Virginia mallow plants.

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Streszczenie

Pył uliczny jest jedną z bardziej toksycznych substancji w środowisku. Liczne doniesienia literaturowe potwierdzają, że poprzez odpowiednie nasadzenia różnych roślin można osłaniać tereny przylegające do tras komunikacyjnych. W ten sposób ogranicza się rozprzestrzenianie różnych zanieczyszczeń, w tym metalami ciężkimi. Celem badań było określenie zawartości cynku ogólnego i przyswajalnego w glebie pobocza drogowego oraz w glebie działki bezpośrednio sąsiadującej z tym poboczem, na której uprawiany był ślaziovec pensylwański, którego nasadzenia miały pełnić funkcję biologicznego ekranu drogowego. Określono również zawartość cynku w poszczególnych częściach ślaziowca pensylwańskiego. Otrzymane wyniki badań wskazują, że zawartość cynku w glebie, na której uprawiany był ślaziovec pensylwański była zbliżona do zawartości w glebie pobocza bezpośrednio przyległego do drogi. Podczas 2-letniego okresu prowadzenia badań nie zaobserwowano zmniejszenia zawartości tego pierwiastka w glebie z obu działek doświadczalnych. Ponadto, najwyższą zawartość cynku stwierdzono w liściach, częściach roślin najbardziej narażonych na zanieczyszczenia motoryzacyjne, niższą w korzeniach, a najniższą w łodygach badanych roślin ślaziowca pensylwańskiego.

1. INTRODUCTION

Potential pollution of soil surrounding intensively used communication routes may be bonded with exhaust gasses emission, with agents used for road maintenance, abrasive wear of road surface, wear of car parts (including tires) and various other emergency situations (leaks of polluting substances from vehicles or from improperly closed tanks) [Klojzy-Karczmarczyk 2013]. The highest pollution of the environment caused by heavy metals of automotive origin is observed in case of areas surrounding communication routes with the heaviest traffic, that is, motorways and express routes. Among heavy metals of automotive origin, lead, cadmium, zinc, copper and nickel are considered to be the most dangerous. Elimination of this type of pollutants does not cancel the hazard for such contamination is considered to be permanent. Plants accumulate heavy metals in various parts – roots, leaves or stems. That is why it is necessary to monitor the content of these elements in soil and plants along communication routes. Intake of

trace elements from polluted soils by plants often exceeds their physiological demand. Excessive amounts of the elements in soil can have phytotoxic effects [Niesiobędzka et al. 2005]. Phytotoxicity is a result of disturbance of physiological processes, which themselves result from disturbance of intake and transport of vital macro- and microelements that negatively affect growth and development of most species of plants. Chemical degradation of soils makes proper growth and development of plants, and hence their cultivation, impossible [Baran et al. 2008]. Covering the surface of soil with dense plant cover is called phytostabilisation; moreover, it limits the erosion of contaminated soils. Plants fulfil a protective role – they prevent erosion; moreover, they stimulate processes of metals sorption in soil and modify water regime, lowering the risk of outwashing metals [Karczewska, Kabala 2010]. Determination of total and available zinc content in soil of the roadside and in soil of a parcel directly neighbouring the roadside on

which Virginia mallow was cultivated, plantations of which were supposed to fulfil a function of a biological road screen, was the aim of the investigation. Content of zinc in particular parts of Virginia mallow, that is, leaves, stems and roots, was also determined.

2. MATERIALS AND METHODS

The research was carried out on the area of Pogórze Przemyskie Landscape Park, where along district road 2085 R Krasieczyn–Korytniki a field experiment was established. Experimental plots sown with Virginia mallow (*Sida hermaphrodita* Rusby) formed a roadside green belt, 15 m in width and 360 m in length. This belt was divided by means of narrow technological paths into two parts characterised with various spacing of plant rows: plot 1 where spacing between rows of plants was 0.75 m and plot 2 where spacing between the rows was 0.50 m. When compared with the road, which was above the surrounding area, the particular experimental fields were at different levels. Difference between the road level and plots 1 and 2 was 0.5–0.6 m and 2.0–2.5 m, respectively. Soil on which the experiment was established, according to classification of classes of soils and mineral materials [PTG 2008], was a clay loam. Content of humus was 2.3%, and content of available forms of major minerals expressed in mg per 100 g of soil was: P – 13.6; K – 22.2; Mg – 8.4 and pH 7.4. In the first year of cultivation, the plots were fertilised with ammonium nitrate (N 34%), single superphosphate (P 19%) and potassium sulphate (K 50%) in the proportion N:P:K = 158:88:116 = 1.8:1:1.3. Nitrogen fertiliser was introduced in two doses. In the second year of cultivation, the amount of fertilisers was lowered and the experimental plots were fertilised with ammonium nitrate (N 34%), single superphosphate (P 19%) and potassium sulphate (K 50%) in the proportion N:P:K = 79:44:58 = 1.8:1:1.3. Nitrogen fertiliser was also introduced in two doses.

The research concerned content of total and available zinc in soil with simultaneous determination of its acidity, and evaluation of zinc content in particular parts of Virginia mallow, that is, leaves, stems and roots. Determination of zinc content in plant samples was conducted in three repetitions.

Soil subjected to analyses was the one directly adjacent to the roadside of road Krasieczyn–Korytniki, sampled approximately 3 m from the edge of the road surface, and soil from plots where Virginia mallow plants were cultivated. Investigation also included particular parts of Virginia mallow plant: leaves, stems and roots. In order to determine zinc content in soil from the roadside depression, when compared with the road surface, eight gross samples made up of 20 primary samples were taken. The samples were taken from depths 0–5 cm and 5–20 cm from sections parallel to plots 1 and 2, respectively. From each experimental plot, 20 primary samples were taken, which then add up to one gross sample weighing 0.5 kg. Primary samples were taken in accordance

with instruction for soil samples of arable land and grasslands, elaborated by Chemical Agricultural Station, in accordance with PN–R–04031:1997 norm. From each experimental plot, samples of particular parts of Virginia mallow plants (leaves, stems and roots) were taken and then dried. Physical-chemical analyses of soil samples and chemical analyses of plant samples were carried out in Chemical Agricultural Station in Lublin. The research was carried out for a period of two subsequent years in the second and third years of conducting the plot experiment.

For the purpose of determination of zinc in plant material samples, PB–16 – ASA method was used. Soil samples were analysed by means of the following analytical methods: pH PN–ISO 10390:1997; determination of available zinc PB–06–PN–R–04016 – ASA method; determination of total zinc PN–ISO 11047:2001, PB–17 – ASA method.

3. RESULTS AND DISCUSSION

The value of pH of soil on which Virginia mallow plants were cultivated remained similar throughout duration of the experiment. In the first year it was 7.33 in case of the first plot and 7.40 for soil sampled from the second plot. In the second year, pH was 7.36 and 7.42 for plots 1 and 2, respectively (neutral soil). Gębski [1998] states that bioavailability of Zn is strictly bonded with soil pH. Its mobility increases as soon as pH falls below 6.0. Blake and Goulding [2002] inform that Zn activity increases for pH from 5.5 to 5.0.

Content of total and available zinc in soil of both the experimental plots and soil of the roadside were similar (Table 1). In a course of two years of conducting the investigation, no decrease in both forms of the element was observed in soil of both experimental plots on which Virginia mallow was cultivated.

Zinc content in all analysed samples of soil from area covered by the investigation did not exceed value of permitted concentrations specified in Regulation of Minister of Environment of 09 September 2002 concerning standards of soil quality and standards of land quality [Dz.U.2002.165.1359] and was close to geochemical background (5–100 mg•kg⁻¹) [Lis 1995]. Similarly, content of the element did not exceed mean, natural content for that type of soil, as well as content allowed in soils of arable land [Kabata-Pendias, Pendias 1999].

Zinc is one of the most mobile metals in soil, what is caused by its exchangeable forms and forms bonded with organic matter. Soil organic substances often form durable bonds with zinc, what is a main reason for its accumulation in surface levels of mineral soils and in organic soils. Mean content of zinc for all unpolluted soil of Poland is 40 mg•kg⁻¹. However, in strongly polluted areas, it may reach a couple of thousand mg•kg⁻¹, while content which is considered to be permissible for soil being used for agricultural purposes is 250–300 mg•kg⁻¹ [Kabata-Pendias, Pendias 1999].

Table 1. Content of total and available zinc [mg•kg⁻¹]

		Plot 1	Plot 2	Roadside along plot 1	Roadside along plot 2
Total Zn	First year of the investigation	52.11	60.11	49.45	60.86
	Second year of the investigation	52.78	64.10	52.11	60.11
Available Zn	First year of the investigation	11.36	1.68	12.21	18.60
	Second year of the investigation	12.02	16.90	12.55	18.20

Geochemical background of zinc in soils of majority of the country is low – 50 mg•kg⁻¹. When a type of utilisation of land is taken into consideration, it can be noted that the highest values are observed in soils of parks of Upper Silesia (442 mg•kg⁻¹ on average), soils of city lawns (340 mg•kg⁻¹) and soils of arable fields located within cities (306 mg•kg⁻¹) [Lis 1995].

Content of zinc in particular parts of Virginia mallow varied. The highest concentration of the element was noted in leaves, lower in roots and the lowest in stems of the plants. Analysing content of zinc in leaves, stems and roots of Virginia mallow, it was observed that it did not exceed values considered to be excessive (toxic), that is, 100–400 mg•kg⁻¹. Moreover, it can be stated that it remained within limits for concentration of these elements in various plants having moderate sensitivity to their excess and within limits of content in cultivated plants of Poland [Kabata-Pendias, Pendias 1999].

Statistical analysis of obtained results of investigation of zinc content in particular parts of Virginia mallow did not prove the presence of statistically significant differences, at significance level $\alpha = 0.05$, between content of the element in subsequent years of conducting the research, in leaves and stems sampled from both plots and roots sampled from the first plot. However, statistically significant differences between content of zinc in roots sampled from plot 2 in the first and the second year of conducting the research were noted (Table 2).

Zinc is present in soil in freely soluble forms; hence it is easily available for plants. Vascular plants usually intake zinc proportionally to its concentration in soil, which is why pollution with this metal creates hazard of increasing its presence in a food chain. Lowering phytoavailability of zinc is obtained by means of introduction of calcium, phosphatic fertilisers and compounds of sulphur. Excessive amounts of zinc usually accumulate in roots and leaves [Kabata-Pendias, Pendias 1999]. However, results of research carried out by Ociepa and others [2013] do not indicate clear dependence between total content of heavy metals in soil and plants, yet influence of fertilisation on intake and content of Zn in overground parts of plants was observed. Lower content of the element in plants (about 15.0% decrease), being a result of enriching soils with organic matter and increasing soil pH, what led to limiting mobility and bioavailability of heavy metals, was observed. It should be remembered that significant amounts of organic substance introduced into light soils improve their structure and sorption properties [Wolski, Wolny 2011]. Baran and Jasiewicz [2009] after investigating the concentrations of cadmium and zinc in soil, toxic to various species of plants (flax, pea, vetch, mustard), inform that plants characterise with different sensitivity to excess of the elements, and an important factor determining phytotoxicity of the metals is the species of a plant in question and even its variety.

Moreover, phytotoxicity of the elements for investigated species of plants may also be dependent on interactions with other elements, which can affect the course of physiological processes.

4. SUMMARY AND CONCLUSIONS

One of the most serious environmental problems bonded with development of motorisation is global emission of heavy metals, and solution to this problem is of great importance when balanced development is considered [Pawłowski 2011]. Presenting structural and spatial diversity of soil pollution with heavy metals is a base for rational programming investment activity concerning protection of the environment aiming at removal of structural and spatial disproportions [Gawroński 2002]. Assessing the scale of threat to environment posed by heavy metals, being a result of automotive pollution, is of key importance for the process of designing roads. It enables introduction of efficient engineering methods serving a purpose of environmental protection. In light of research which has been conducted since the 1990s, the hope was and is placed on the possibility of utilisation of the methods of phytoremediation and especially phytoextraction. These methods, which are non-invasive and therefore environment friendly, have gained a lot of interest. However, the method of phytoextraction of heavy metals from soil is usually not very effective and does not give a chance of removing significant amounts of the metals from soil within a realistic time of a dozen or so or even several dozen years [Karczewska, Kabala 2010].

Relying on analysis carried out and the research results, the following conclusions were drawn:

1. Concentration of zinc in soil of area directly adjacent to the road Krasiczyn–Korytniki and soil on which Virginia mallow was cultivated did not exceed the permitted level and was similar to geochemical background of the area.
2. Reaction of investigated soil was neutral; pH ranged from 7.33 to 7.42, and did not fall below 6 when bioavailability of zinc for plants increases.
3. Content of zinc in particular parts of Virginia mallow was not excessive (toxic). The highest concentration of zinc was noted in leaves of Virginia mallow, the part of the plant which is the most exposed to automotive pollution.
4. Statistical analysis of research results, obtained during subsequent years of conducting the investigation, did not show statistically significant differences of zinc content in leaves and stems of Virginia mallow sampled from both experimental plots and in roots sampled from the first plot. However, statistically significant differences between content of zinc in roots sampled from plot 2 in the first and the second year of conducting the research were noted.

Table 2. Content of zinc in leaves, stems and roots of Virginia mallow [mg•kg⁻¹]

	No of plot	First year of the investigation				Second year of the investigation			
leaves	1	36.2	31.85	30.55	32.87 ^a	47.40	33.70	41.30	40.80 ^a
	2	37.60	29.25	35.60	34.15 ^a	45.80	50.90	39.20	45.30 ^a
stems	1	7.00	5.50	5.89	6.13 ^a	10.10	6.40	6.30	7.60 ^a
	2	7.76	5.65	4.26	5.89 ^a	7.45	6.95	7.70	7.37 ^a
roots	1	14.10	16.75	14.7	15.18 ^a	20.80	18.40	14.90	18.03 ^a
	2	15.15	17.45	12.70	15.10 ^a	20.30	22.20	24.00	22.17 ^b

^{a, b} – Mean in rows marked with various letters in index mean that significant ($\alpha = 0.05$) differences between investigated properties were noted

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