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Short Communication

Limiting the Environmental Impact of Road Infrastructure through the Use of Roadside Vegetation

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Abstract

Green-belt shielding seems to be the right solution for protection against the spread of automotive environmental pollution, particularly when it comes to large areas. Roadside greenery fulfills a range of various functions – both natural and aesthetic, while also offering great potential for environmental protection. The aim of this study was to determine the content of zinc and copper in the soil collected from a roadside, as well as in soil collected from immediate surrounding areas where Virginia mallow (*Sida hermaphrodita* Rusby) was grown as a form of biological roadside screen barrier, and to examine how the vegetation in this area may limit the spread of automotive environmental pollution. Furthermore, the content of the researched elements in the separate parts of the plants (leaves, stems, roots) collected in varying proximity of the road was specified. The highest concentration of copper was found in the leaves and roots of the Virginia mallow, whereas that of zinc was in the leaves of the plant.

Keywords: automotive environmental pollution, copper, zinc, roadside vegetation

Introduction

Heavy metals constitute some of the most dangerous roadside pollution [1]. Their emission in and around roads and motorways is generally limited in its spatial range. The highest accumulation is found in the soils and plants within 20-40 meters of the road, it gets lower as the distance to agriculture areas increases, and it is slight within the distance of 100-150 meters [2].

Heavy metals emitted to the environment by automotive pollution first and foremost is derived from fuel combustion processes, exploitation fluids and liquids, and those resulting from the wear and tear of the individual car parts, including the engine, brakes, clutches, and tires. A range of various elements, including heavy metal elements, occurs in crude oil and its derivative products of engine petrol and diesel fuel oils. These may also include additives used for fuel or existing in the form of pollution. The above also infiltrate the natural environment while being released in the operation of the communication infrastructure, as a result of the wearing of asphalt surfaces, as well as the corrosion of noise barriers, traffic barriers, and road signs. Some of the substances settle on the surface of the roads, while some are diffused in the immediate proximity of the road. Particulates are the carriers of heavy metals, on the surface of which they are, among other things, absorbed. Road dust is one of the most toxic substances in the environment. There is a fairly large number of heavy metals which can, in this precise way, enter the environment [3].

Among heavy metals of automotive origin the most dangerous are lead, cadmium, copper, and nickel. They accumulate in the soil and plants and thus are incorporated

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into the food chain, and subsequently gather in animal and human tissues [4]. These metals are often not excreted from the organisms, but are amassed within the bones, the kidneys, the liver, and the brain, contributing to the emergence of various diseases, including cancer. The content of these precise elements in soil along communication routes is most often monitored. It is also crucial to monitor the content of these elements in individual parts of the plants occurring in the areas of immediate vicinity to communication routes. Plants accumulate heavy metals in a variety of their organs – in the roots, leaves, or stems. It is therefore vital to determine the magnitude of the environmental risk of heavy metals resulting from communication pollution. All the undertaken actions allow the introduction of rational engineering solutions at the road design stage, which would increase environmental protection.

One of the energy crops recommended for cultivation on marginal soils that is resistant to unfavorable conditions and boasts high environmental plasticity while simultaneously possessing satisfactory plant yield potential and favourable characteristics of biomass energetic parameters is Virginia mallow (*Sida hermaphrodita* Rusby) [5-7].

The aim of this study was to determine the content of zinc and copper in soil collected from the roadside, as well as in the soil collected from immediate surrounding areas where Virginia mallow (*Sida hermaphrodita* Rusby) was grown as a form of biological roadside screen barrier. Furthermore, we examined how the vegetation in this area may limit the spread of automotive environmental pollution. Subsequently, the content of the researched elements in the separate parts of plants (leaves, stems, roots) collected in varying proximity of the road was specified.

Research Methodology

The research was carried out in the Pogorze Przemyskie Landscape Park with a field experiment set up along the district road 2085 R Krasiczyn-Korytniki. Experimental plots sown with Virginia mallow constituted a roadside greenery belt 15 m wide and 360 m long. The belt was divided with narrow technological paths into two parts differentiated by spacing between rows of plants: Plot No. 1 with 0.75 m spacing between rows of plants and Plot No. 2 with 0.50 m spacing between rows. Experimental fields were set up on various levels in relation to the road surface (road surface above the surrounding area level). The difference between the road level and Plot No. 1 was approximately 0.5-0.6 m, and between Plot No. 2 approx. 2.0-2.5 m.

The soil on which the experiment was set up, according to the classification of soil and mineral composition granulation of the Polish Society of Soil Science (PSSS) [8], was clay loam. The content of humus equaled 2.3%, the content of vital minerals in easily assimilated forms in mg to 100 g of soil equaled: P –13.6; K – 22.2; Mg – 8.4, and pH 7.4. In the first year of cultivation the plots were fertilized with ammonium nitrate (N 34%), single superphosphate (P 19%), and potassium sulfate (K 50%) in the following proportions N:P:K = 158:88:116 = 1.8:1:1.3. Nitrogen fertilization was introduced in two doses. In the second year the amount of fertilizer was decreased and experimental plots were fertilized with ammonium nitrate (N 34%), single superphosphate (P 19%), and potassium sulfate (K 50%) in the following proportions N:P:K = 79:44:58 = 1.8:1:1.3. Nitrogen was also introduced in two doses.

The subject of the research was the content of zinc and copper total assimilable in the soil while simultaneously determining its pH, as well as the evaluation of the content of these elements in individual parts of Virginia Mallow (leaves, stems, roots) collected in varying proximity to the road. The object of the study was the soil from the immediate surrounding area of the Krasiczyn-Korytniki roadside, collected within the distance of approx. 3 m from the verge of the road, as well as the soil collected from the Virginia Mallow cultivation site. Samples of individual parts of Virginia Mallow (leaves, stems, roots) were also collected from each of the experimental plots and then dried. The samples were collected from the greenery belt situated closest to the road (7 m from the verge of the road), from the middle of the greenery belt (15 m from the verge of the road), as well as from the part situated the farthest from the verge of the road (22 m). So as to determine the contents of zinc and copper in the soil, eight general samples composed of 20 incremental samples were collected from the roadside slope. The samples were collected at a depth of 0.5 cm and 5-20 cm for sections parallel to plot No. 1 and 2, respectively. 20 incremental samples were collected from each experimental plot comprising one main sample weighing 0.5 kg. Incremental samples were collected in compliance with the soil sampling instructions for arable lands and grassland developed by the Chemical and Agricultural Research Laboratory in accordance with PN-R-04031:1997.

The physicochemical analysis of the soil samples and the chemical analysis of the plant samples were performed at the District Chemical and Agricultural Research Laboratory in Lublin. The study was carried out for two consecutive years, in the second and third year of the use of the field experiment.

When analyzing mineral soil samples the analytical methods pH PN-ISO 10390:1997 were used, determination of the zinc and total copper content: PN-ISO 11047:2001, PB-47 – AAS method, determination of the assimilable copper content: PB-06-PN-R-04017 – AAS method, determination of the assimilable zinc content PB-06-PN-R-04016 – ASA method. The analysis of plant sample material: determination of zinc and copper content: PB-16 – AAS method.

Research Results and Discussion

The pH value of the soil whereon Virginia Mallow was cultivated were similar; in the first year of conducting the research pH equaled 7.33 in the soil collected from Plot No. 1 and 7.40 in the soil collected from Plot No. 2, and in the soil from the roadside of Plot No. 1 it was 7.33 and in the

Table 1. The content of total and assimilable copper and total and assimilable zinc.

		Plot No. 1	Plot No. 2	Roadside of Plot No. 1	Roadside of Plot No. 2
Cu total [mg·kg^{-1}]	First year of research	14.12	15.78	13.39	15.95
	Second year of research	13.15	16.35	13.90	14.58
Cu assimilable [mg·kg^{-1}]	First year of research	7.80	8.81	6.62	8.28
	Second year of research	8.27	10.05	7.16	8.81
Zn total [mg·kg^{-1}]	First year of research	52.11	60.11	49.45	60.86
	Second year of research	52.78	64.10	52.11	60.11
Zn assimilable [mg·kg^{-1}]	First year of research	11.36	14.68	12.21	18.60
	Second year of research	12.02	16.90	12.55	18.20

soil from the roadside of Plot No. 2 it was 7.39. In the second year of conducting the research the pH equaled, respectively, 7.36 and 7.42 in Plot No. 1 and 2, and 7.39 and 7.49 in the soil from the roadside of Plot No. 1 and 2. The soils were neutral.

The pH value is considered to be one of the main factors influencing the form in which heavy metals occur in the soil environment, as well as their availability for plants [9-11]. Reduction of the soil pH value to slightly acidic and acidic causes increase in the soil solution concentration available for plants' moveable forms of heavy metals, thus increasing the indicator of their accumulation [9, 10]. Gębski [10] states that Zn is one of the elements most susceptible to the pH value alteration. Its mobility already increases with the pH value drop below 6-6.5, whereas Cu demonstrates such a feature not until pH < 5.0, while Blake and Goulding [12] note that Cu and Zn activity increases at pH 5.5-5.0. The pH value of the researched soil was neutral, ranging between 7.33-7.49, without decreasing below the values for which bioavailability of copper and zinc for plants increases.

The content of total and assimilable forms of researched elements in the soil from both experimental plots and from the soil collected from the roadside was similar (Table 1). During the two years of conducting the research there was no noted decrease in the content of both forms of these elements in the soil from both experimental plots where Virginia Mallow was cultivated.

Tests on leaching of heavy metals from road dust conducted by Krajewska and Niesiobędzka [13] indicate the possibility of transferring significant amounts of metals from dust into soil solution and subsequently into the plant root system. The accumulation of heavy metals in the soils, in particular in a form easily available to plants, may constitute the direct cause of excessive absorption of such metals by plants. Research conducted by Palak et al. [14] indicated the accumulation of heavy metals in grass sward along communication routes in the following order Zn > Cu > Pb > Cr > Cd. Moreover, Wowkonowicz et al. [15] demonstrated significant correlations between total content of Cu and Zn in the soils and their bioavailable forms. Parzych and Jonczak [16] indicated that the content of heavy metals (Zn, Cu, Mn, and Fe) in the pine needles of *Pinus sylvestris* was diversified depending on the metal, pine age, and humidity of the forest complex.

The content of copper and zinc in all of the analyzed soil samples did not exceed exposure limit values according to the Regulation of the Ministry of the Environment of September 9, 2002, concerning the standards of soil quality and standards of earth quality [17], and it was similar to the geochemical background (Cu 20-40 mg·kg^{-1}, Zn 5-100 mg·kg^{-1}) within the area of conducted research [18]. Likewise, the content of these elements did not exceed the average natural content within this type of soils, nor did it exceed the admissible content in the soils used for agricultural purposes [11].

The average content of copper in Polish soils equals 6.5 mg·kg^{-1} within a 0.2-752 mg·kg^{-1} range. In the soils found in the vicinity of transport routes, an increased content of copper was stated. The average content of copper in Polish soil is low (< 10 mg·kg^{-1}) and large areas of the country are characterized by the shortage of this element with relation to the needs of plant organisms. Clay soils of southern Poland are richer in copper (20-40 mg·kg^{-1}). The recorded content of total copper amounted to 13.15-16.35 mg·kg^{-1} (Table 1) and remained within the limits of the geochemical background.

The average content of zinc for all unpolluted soils in Poland is 40 mg·kg^{-1}. However, within highly polluted areas it may increase even to a few thousand mg·kg^{-1}. The admissible content of zinc in the soils used for agricultural purposes was determined at the level of 250-300 mg·kg^{-1} [11]. The content of total zinc in the researched soil samples remained within the 49, 45-60, and 86 mg·kg^{-1} range (Table 1), and was within the limits of the geochemical background.

The research results of the content of copper and zinc obtained within two vegetation seasons in the individual parts of Virginia Mallow (leaves, stems, roots) collected in varying proximity of the verge of the road of the experimental plots are shown in Table 2.

The analysis of the content of copper and zinc in the leaves, stems, and roots of Virginia Mallow revealed that it did not exceed values considered excessive (toxic), equaling for copper 20-100 mg·kg^{-1} and for zinc 100-400 mg·kg^{-1}.

Table 2. The content of copper and zinc in leaves, stems, and roots of plants from Plot No. 1 and 2.

			First year of research			Second year of research		
			Proximity from the road [m]			Proximity from the road [m]		
			7	15	22	7	15	22
Plot No. 1	Cu content [mg·kg^{-1}]	leaves	7.41	7.41	4.67	8.26	7.71	8.13
		stems	2.53	2.53	1.97	2.69	2.07	2.36
		roots	7.02	7.88	5.23	10.44	8.04	6.78
	Zn conent [mg·kg^{-1}]	leaves	36.20	31.85	30.55	47.40	33.70	41.3
		stems	7.00	5.50	5.89	10.10	6.40	6.30
		roots	17.10	16.75	14.7	20.80	18.4	14.90
Plot No. 2	Cu content [mg·kg^{-1}]	leaves	6.06	5.84	4.69	5.97	8.74	9.68
		stems	2.59	2.40	1.75	2.5	2.43	2.53
		roots	7.16	7.71	4.87	7.01	8.92	9.64
	Zn content [mg·kg^{-1}]	leaves	37.60	29.25	35.6	45.80	50.90	39.20
		stems	7.76	5.65	4.26	7.45	6.95	7.70
		roots	15.15	17.45	12.7	20.30	22.20	24

Moreover, it can be stated that it remained within the limits of the content of these elements in various plants with moderate sensitivity to its excess, as well as in the limits of the content in arable crops in Poland. According to Kabata-Pendias and Pendias [11], the physiological norm amounts to 5-30 mg·kg^{-1} for copper and 25-150 mg·kg^{-1} for zinc.

The highest content of copper was determined in the leaves and roots of Virginia Mallow, and the highest content of zinc in the leaves of the plants under research. The lowest content of the analyzed elements was stated in the stems. During two years of research the lowest content of copper was found in the leaves of Virginia Mallow collected 15 and 22 m from the verge of the road. What is more, a similar tendency for copper and zinc content changes was observed in the roots of Virginia Mallow during both years of conducting research on Plot No. 1 and during the first year of research on Plot No. 2.

A significant impact of the vegetation surrounding communication routes on decreasing the content of heavy metals in the soil was proven by the research of Czubaszek and Bartoszuk [19]. They stated the lower content of Pb, Ni, Cr, Cd, and Cu in the soil collected from woodland areas in relation to areas on the other side of the road with poor vegetation coverage.

Conclusions

The potential soil pollution around intensely used auto routes is connected with the emission of exhaust fumes, the use of road maintenance agents, the abrasion of road surface, and the wear and tear of car parts (including the tires), as well as various emergency situations (leakage of pollutants from vehicles or from leaking tanks) [20, 21]. The energy efficiency of the vehicle is also associated with the impact on the environment [22]. Road dust constitutes a significant source of pollution of other environmental components with heavy metals [3]. Within the soils and surface waters of urbanized regions the heavy metal concentration level has long exceeded the natural geochemical background [10, 23]. The global emission of heavy metals is one of the major environmental concerns connected with the development of the automotive industry and the solution to this problem is crucial in terms of the sustainable development perspective [24].

Green-belt shielding has proven to be an extremely beneficial solution for protection against the spread of automotive environmental pollutions, especially large areas. Roadside greenery fulfills a range of diversified functions, both natural and aesthetic, while at the same time offering great possibilities in terms of environmental protection. Numerous research has confirmed that through the adequate planting of diverse greenery it is possible to shield areas adjacent to communication routes. This solution limits the spread of various pollutions, including heavy metals.

On the basis of the conducted research and the analysis of its results, the following conclusions were reached:

1. The pH value of the tested soil was neutral, the pH remaining within the range of 7.33-7.49, without decreasing below the values for which the bioavailability of copper and zinc for plants increases.
2. The pollution of the tested soils with the selected heavy metals was slight. Its content did not exceed the admissible limit and was similar to geochemical background within the area.

3. The content of copper and zinc in individual parts of Virginia Mallow was not excessive (toxic). The highest concentration levels of copper were established in the leaves and roots of Virginia mallow, while that of zinc in the leaves of the plant.
4. The roadside greenery belt in the form of planted Virginia Mallow limits the spread of heavy metal from automotive sources, the plants retain and accumulate heavy metals mostly in the leaves, as well as the roots, thus causing their immobilization.

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