Heavy metals in the vascular plants of Tatra Mountains

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Introduction

Heavy metals deriving from anthropogenic activities are important pollutants in the environment. The term "heavy metals" is used for the group of elements with the density higher than 5 g.cm⁻³. Some of them are necessary for living organisms (Cu, Zn, Mn, Cr, Co), but they can have a toxic effect in the greater amounts. The others are inessential and risk due to their toxicity and ability of accumulation in soils and organisms because they are not degradable. Heavy metals naturally occur in pure form or in salts and can be transported in biological and geochemical cycles. Anthropogenic emissions originate mainly from mining, industrial production, combustion of fossil fuels and application of fertilizers and pesticides.

Plant uptake of heavy metals in relation to their content in soil

Metals of anthropogenic origin are generally considered as more available from soils than those originating from parent rock (Grupe and Kuntze 1988). Effects of heavy metal pollution are most long lasting in soils due to relatively strong adsorption of many metals onto the humus and clay colloids. The duration of contamination may be for hundreds and thousands years in many cases, e.g. first half lives: Cd 15 – 1,100 years, Cu 310 – 1,500 years and Pb 740 – 5,900 years depending on the soil type and physico-chemical parameters (Alloway and Ayres 1994).

The form in which the metals are present in the soil, i.e. metal speciation, greatly influences the rate of their uptake. Metals in soil solution, exchangeable metals and organically bound metals are considered as easily or potentially available (Kabata-Pendias and Pendias 1992). The heavy metals generally regarded as highly mobile in soils are Mn, Cd, Co, Zn, Ni, on the contrary, Pb, As, Cu are characterised by lower mobility in soils. The important parameters for the input of heavy metals from soil into plants are: soil reaction, content and quality of organic matter, nutrition of plants, cation exchange and sorptive capacity, microbiological activity, oxidation and reduction potential, amount and quality of the clay fraction of soil and method of soil cultivation (Alloway 1990).

Barančíková (1998) divides heavy metals depending on pH values into two groups: the former contains elements as Cd, Cr, Pb, Zn and Ni that dispose of maximal mobility in soil at pH lower than 5.5. The latter is typical for Cu and As with maximal mobility below 4.5 and above 7.0. The mobility of Hg is independent of the soil reaction. The quality of soil organic matter significantly influences behaviour of heavy metals and their bioavailability. Humic acids share in retaining of heavy metals and decreasing of their content in soil solution (Brümmer et al. 1986). On the other hand fulvic acids and their complexes can increase mobility and toxicity of heavy metals. Some elements are characterized by high affinity to organic matter in soil, e.g. Pb and Cu. The mineral part of soil plays an important role in immobilization of metals, especially chemisorption, irreversible process, and reversible electrostatic adsorption belong to mechanisms that can be used in soil detoxication.

Heavy metal contamination of soils in mountainous regions of Slovakia is at the margin of interest, main attention is devoted agricultural soils. Kobza (2002) noted that in accordance with obtained results contamination of mountainous soils is at the foot of the High and Low Tatras and their transfer into agricultural plants. The results of monitored heavy metals prove that portion of Cd and Ni is the main polluting factor of soils in this region. Hajdúk (1988) ascertained the content of some heavy metals in TANAP soils in relation to the effect of industrial emissions. Pb content near the trunk of a beech tree (Fagus sylvatica) close to a gully was higher by 100 % and Cu by about 50 % than at a distance three metres away. Near rocky walls, Pb content in most samples proved to be higher than or at least equa to that in soil 2 – 8m from the rock. Above mentioned facts support the theory that higher concentrations of some metals reveal in the localities, where these elements are washed up by the rain water from larger surfaces on smaller ones. Heavy metal deposition in Tatras mountain relates with automobility and on northern aspects there is evident the effect of transboundary air pollutants from Poland (Katowice). In the highest ridge positions without terrain barriers is prevailing north-west convection (Konček et al. 1973).

Heavy metals in plants

Plant uptake of metals is generally dependent on (1) movement of elements from the soil to the plant root,
(2) elements crossing the membrane of epidermal cells of the root, (3) transport of elements from the epidermal cells to the xylem, in which a solution of elements is transported from roots to shoots, and (4) possible mobilization from leaves to storage tissues in the phloem transport system (John and Leventhal 1995). Metal mobility in plants is various and decreases in the order Zn > Cd > Pb (Borůvka et al. 1997a). In plants, some metals are accumulate in roots (especially Pb), probably due to some physiological barriers against metal transport to aerial parts, while others are easily transported in the plants, for example Cd (Kabata-Pendias and Pendias 1992).

According to Baker (1981), there are three basic types of tolerance strategy to heavy metals: (1) induction – the content of metals in the plants reflects their quantity in external environment, (2) exclusion – the uptake and transport of metals are restricted, the metals are immobilized in root system, (3) accumulation – the plants due to specific physiology active concentrate the metals in aerial parts. The extreme level of metal tolerance in vascular plants is hyperaccumulation. Hyperaccumulators are defined as higher plant species whose shoots contain > 100 mg Cd kg\(^{-1}\), > 1,000 mg Ni, Pb and Cu kg\(^{-1}\), or 10,000 mg Zn and Mn kg\(^{-1}\) (dry weight) when grown in metal-rich soils (Baker and Brooks 1989, Baker et al. 1994). *Thlaspi caerulescens* is the example of hyperaccumulator in Slovakia, *T. caerulescens* ssp. *caerulescens* can accumulate 30 g Ni kg\(^{-1}\), 43 g Zn kg\(^{-1}\), 2 g Cd and Pb kg\(^{-1}\), *T. caerulescens* ssp. *latense* accumulates 20 g Zn kg\(^{-1}\) dry weight (Dercová et al. 2005). The accumulation capacity of these plants can be used in the phytoremediation techniques to eliminate metal contamination of large areas.

The toxicity of heavy metals generally declines in order: Hg > Cd > Ni > Pb > Cr and lies in substitution of the essential metals in the enzymes and in the important biomolecules (Makovníková et al. 2006). Recently the great attention has been devoted to their content and cumulation in agricultural plants. It is very important to research heavy metal loading of the natural ecosystems for assessment of environmental contamination. Matíková et al. (2008) investigated the atmospheric loading of the Slovak Carpathians using bryophyte technique. In comparison to the median northern Norway values of heavy metal contents in moss the Slovak atmospheric deposition loads of the trace elements were found to be higher than average. Kuklová and Kukla (2007) determined the content of risk elements (Cd, Hg, Al, Pb, Ni, Cr) in aboveground phytomass of herb species selected in spruce ecosystems of Central Spis Region. The concentration of Al, Ni, Pb, Cd and Hg in the species *Vaccinium myrtillus, Luzula luzuloides* and *Dryopteris dilatata* were mostly found exceeding the limits of natural occurrence of these elements in plants.

In mountainous regions, arising altitude, local orographic and related meteorological conditions determine the distribution of heavy metal atmospheric deposition. Investigation of differences in heavy metal deposition in respect to different altitudes seems to be necessary. Generally it is known that there is a strong correlation between orography, the amount of wet deposition and rainfall composition (Fowler et al. 1993). The rate of atmospheric element deposition in mountains may vary within short distances. Although precipitation generally increases with altitude along transects in small mountainous areas (Zechmeister 1995), the precipitation pattern is usually affected by a complex interplay of factors, especially geographic
Heavy metals in the vascular plants

Heavy metals often in lower concentrations impact as stress factor for many sensitive plants. Stunted growth, chlorosis and necrosis, leaf epinasty and red-brownish discoloration are visible symptoms of metal phytotoxicity. At the metabolic level, enzyme capacity can be substantially inhibited. Contaminated plant nutrition represents potential risk for herbivores and through the food chain for carnivores with the ability of cumulation. Mountainous and alpine regions belong to more sensitive ecosystems affected besides by local pollutants mainly by the long-range transport of emissions.

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