Element concentrations in forage plants grown on power station ash deposit

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Abstract

Intensive livestock production is concentrated in the northern part of Serbia, particularly in the vicinity of Belgrade. This area is very important for forage production, but the main power stations of the Serbian power supply system are located in this region and these produce high emissions of fly ash. Forage plants are exposed to the pollution effects of fly ash, and some agricultural systems are located very close to the Nikola Tesla A (TENT-A) power station. A study of three forage plants (*Medicago sativa, Phalaris arundinacea*, *Melilotus officinalis*) was done on 'TENT-A' ash deposit in order to analyse bioaccumulation of maximally exposed plants. Plant samples were collected at tillering stage and concentrations of 10 elements were analysed. The results show lower concentrations of trace metals in the herbage shoots than in the ash, which had excessive contents of As, Ni and Cr. None of the examined species accumulated a high amount of the above-mentioned elements, even though they were from different families, with different morphology and dry matter yield. Alfalfa had the highest concentrations of As and Ni among the species that were analysed.

Keywords: *Medicago sativa, Phalaris arundinacea*, *Melilotus officinalis*, trace elements

Introduction

The use of coal to produce electricity in the 'TENT-A' thermal power station in Obrenovac, Serbia requires large quantities of coal annually. The production of by-products of coal combustion is very large and the vegetation of the region is exposed to emissions of different types of pollutants (Pavlović *et al.*, 2004). To prevent ash dispersion by wind, spare lagoons are covered by vegetation, consisting of adaptive grass-leguminous species. There is interest in studying bioaccumulation in plants because they form the base of the food chain and also because of their potential use in phytoextraction. Absorption depends upon the availability of the metal rather than the total amount of metal in the soil (Kelepertsis and Andrulakis, 1983). Uptake of heavy metals by plants is largely a function of the physiology of the species and the availability of the element concerned. Since coal residues contain potentially hazardous substances, improper handling and disposal could cause undesirable environmental effects (Adriano *et al.*, 1980). The latter may be influenced by the strength of organometalic complexes in the soil. The study reported here covered three species: alfalfa (*Medicago sativa* L.), reed canarygrass (*Phalaris arundinacea* L.) and sweetclover (*Melilotus officinalis* (L.) Pall.). The primary objective of this research was to evaluate trace element concentrations in plant shoots, on a site at the Obrenovac ash deposit site, which is very close to the Serbian capital and main livestock production area of Serbia. The high concentrations of pollutants in the air and those contained in the ash in these areas are considered severe stress factors for the metabolism of plants. Since the thermal power station of TENT-A and the ash disposal sites are in the vicinity of a densely populated area, the same pollutants could be potentially detrimental to the health and well-being of animals and humans.

Materials and methods

For the purpose of determining the concentrations of metals and microelements in plants (alfalfa, reed canarygrass, sweetclover), samples were collected from ash deposits at the TENT-A power station in Obrenovac in May 2005, at the stage of full vegetative development. Plant material was washed in deionized water, then dried at 25 °C, digested with ccHNO_3 and the concentrations of As, Pb, Cd, Hg, Zn, Cr, Ni, Fe, Cu and B in the upper plant parts were measured using spectrometry (Perkin-Elmer 5000 for AAS and FES techniques; MHS-10 (hydride technique); MHS-1 (cold vapour technique), as well as by atomic emission spectrometer with inductively coupled plasma, Perkin-Elmer ICP/6500, MHS-10/5000,0). The concentration of macroelements (N, P_2O_5, K_2O and Ca) in the ash was determined after melting with lithium borate, lithium tetra-borate and lithium iodide, at 1000 °C. The results were processed by calculating average value and standard deviation for each sample. The following analytical methods were applied: for metal determination in plants – AOAC 986.15, and for the determination of other elements in plants – AOAC 985:01. Analysed substrate was neutral in reaction (pH [KCl]7.03), with low P and N content (P<1 mg kg^{-1}), and well-supplied with available K.

Results and discussion

The concentrations in the soil of As, Cr and Ni exceeded the maximum permissible concentrations. Various plants grown on ash deposits that had elevated As, Ni and Cr contents (Table 1) were analysed for their contents of heavy metals and microelements. The observed range of Zn in the plants from the ash deposit was below the critical concentration for normal plant growth. On the other hand, although the ash deposit was contaminated by As, concentrations of As in plants were around 1 mg kg^{-1}, which was below the tolerated concentrations for fodder. Lead (Pb) is considered to be the metal with the lowest biological accessibility and all the examined species had low contents (<1 mg Pb kg^{-1}). The measured content of Cd in ash was low and Cd was neither readily soluble nor easily phytoavailable. The Hg concentration was <0.2 mg kg^{-1} in the deposit and, consequently, the Hg concentration in plant tissue samples was also low. Total Cr content in ash was twice that of the maximum permissible amount and its concentration in all the analysed samples of plant material ranged from 1.19 (sweetclover) to 3.20 mg Cr kg^{-1} (reed canarygrass). The Ni content measured in fly ash was two-and-a-half times higher than the amount allowed in the soil. The highest accumulation level was noted in alfalfa (8.97 mg kg^{-1}), while the lowest level was in reed canarygrass (3.01 mg kg^{-1}), both of which were below the critical concentration for normal plant growth. For these species, the Cu concentrations were found to be within the normal range. According to Adriano *et al.* (1980), there is a toxic effect of B at concentrations of more than 100 mg kg^{-1}; this amount was not observed in plants from the deposit, although the concentration was near critical in *Melilotus officinalis* (99 mg kg^{-1}). Analyses showed a lower bioaccumulation of some elements in alfalfa grown and collected in the ash deposit of 'TENT-A', in comparison with the results reported for alfalfa grown under the same conditions: in their studies Dželetović and Filipović (1995), found fivefold lower concentrations in Pb and Cd, and threefold lower concentartions for Zn and Cu. A possible reason for the difference in concentrations in plant tissue was the higher element concentration observed in the substrate in previous studies. However, the As and Ni content in alfalfa is slightly higher than the range for plant tissue of other herbaceous plants. Although some elements (As, Ni, Cr) exceeded the maximum permissible amounts for soil and water, the ability of plants collected from the ash deposit to accumulate micronutrients was generally low. This could be explained by the pH of fly ash, which influences the relatively low mobility of trace elements in soil solution and, consequently, low uptake by plants (Kabata-Pendias, 2010).

Conclusions

Based on the results obtained, it could be concluded that the three forage species grown on the ash deposit of a coal-fired power station did not hyperaccumulate any of the ten heavy metals and micronutrients that were monitored in this work. Although As, Cr and Ni contents exceeded the maximum permissible

Table 1. pH-value and chemical composition of deposit and trace elements concentrations in herbage from the TENT A ash deposit (mg kg^{-1}).

Deposit depth 0-20		Ash deposit	MTA[1]	*Phalaris arundinacea*	*Medicago sativa*	*Melilotus officinalis*	MTL[2]
As	mg kg^{-1}	34.7	25	1.24	1.80	0.84	4
Pb	mg kg^{-1}	56.7	100	0.65	0.24	0.78	40
Cd	mg kg^{-1}	0.8	3	0.05	0.03	0.10	1
Hg	mg kg^{-1}	<0.2	2	0.44	0.74	0.29	1-8
Zn	mg kg^{-1}	75.9	300	24.3	15.3	23.5	2,000
Cr	mg kg^{-1}	205	100	3.20	1.49	1.19	1-10
Ni	mg kg^{-1}	123	50	3.01	8.97	5.61	50
Fe	g kg^{-1}	21.7	-	180	180	180	1,250
Cu	mg kg^{-1}	62.7	100	2.64	2.61	4.70	12-50
B	mg kg^{-1}	0.71	-	76.5	83.7	99.0	-

[1] Maximum tolerated amount in the soil (Kabata-Pendias, 2010).

[2] Maximum tolerated level for fodder (NRC, 2005).

concentrations in the nutritive medium, their values did not exceed levels considered as the threshold for fodder plants. Iron, boron and zinc were the most prevalent elements in plant tissues, in absolute values. Alfalfa had the highest concentration of As and Ni among the species that we analysed. High pH level, antagonistic relationships among elements and their interactions, as well as physiological features of plants are factors that led to low metal and microelements accumulation in alfalfa, reed canarygrass and sweetclover. The concentrations of trace elements did not exceed values that are taken as tolerable in forages, as prescibed by normatives for ruminants' feed.

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