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EFFECT OF HEAVY METALS FROM MINE SOILS ON *Avena sativa* L. AND EDUCATION STRATEGIES

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ABSTRACT

Heavy metals in the soils of old mining areas, besides affecting the productivity of their ecosystems, could also affect animal and human health. To test this hypothesis, we assessed the bioavailability of heavy metals to forage crops used as human food sources or components of fodder. The sites examined were the surrounding soils of two abandoned mines in Central Spain polluted with Al, Fe, Mn, and more than one of the heavy metals Zn, Pb, Cd, Cu, Cr or Ni, and As. All elements were determined by plasma emission spectroscopy with the exception of As, which was quantified by XRF.

Levels of Zn, Pb, Cd, Cu and Fe were high in roots as well as in the above-ground parts of the plants, and high As levels were also found in roots. The accumulation of heavy metals by this plant was assessed in terms of its possible use for phytoremediation but also in view of its possible detrimental impacts on humans as well as wild and domestic animals.

Strategies for education in areas faced with this problem are also proposed. People living in rural areas will need to be taught ecological concepts but we will also have to alert political leaders and administrators to the problem to encourage them to invest in dealing with polluted soils. In this context, it is essential to understand both the elements and processes affecting ecosystems and the perception and opinions held by the rural population of the problem of soil pollution.

KEYWORDS: Ecosystems health, grasslands, agrosystems, polluted soils, phytoremediation

INTRODUCTION

The environment plays a major role in the health of individuals and communities, including air, water and soil, through which exposure to chemical, biological and physical agents may occur [1]. For several decades, Central Spain has sustained substantial mining activities. Although presently abandoned, the effects of these mines persist [2, 3]. The ecosystems affected by old mines are mainly grasslands consumed by cattle and sheep that are often surrounded by lands given over to forage crops, mainly barley, wheat and oats. These sites show more than one heavy metal in their topsoil layers. Thus, the heavy metals in soils of these Mediterranean ecosystems, besides affecting the productivity of the systems, could also have impacts on animal and human health. Heavy metals detected in the aerial portions of grazing and forage plant species pose a serious health risk for herbivores. Cu and Pb are both toxic with the latter being moderately toxic for plants and highly toxic for animals; Zn and Cr also have known toxic effects. This study was designed to determine the bioavailability of heavy metals to oats used as a food source or component of fodder.

MATERIALS AND METHODS

Two old mines (copper and silver) in Central Spain and their surrounding soils were examined. The copper mine is located in Garganta de Los Montes, Madrid, and the silver one in the province of Toledo. The soils were found to contain more than one of the heavy metals Zn, Pb, Cd, Cu, Cr or Ni, and also As. Samples were collected at random from the topsoil layers (0-15 cm) of the different systems existing in the study area.

Soil samples from the two mine sites were then used to conduct a bioassay in microcosms under controlled conditions planted with *Avena sativa* L. over a 16-week period. Those topsoil layers containing more than three heavy metals and being representative of the different agro/ecosystems of each mine site were chosen and picked up to carry out the assay. Three microcosm replicates were set up for each soil type and mine. Controls were set up using a cropland soil of pH 5.9 and organic matter content of 0.82% lacking high heavy metal levels.

Each microcosm was 19 cm long, 14 cm wide and 10 cm tall. 1 Kg of soil was placed in each microcosm and 5 pre-germinated oat seeds were planted in each one. The assay was carried out in a greenhouse under controlled conditions, essentially maintaining a constant temperature (17.4-24.5 ºC) and humidity (70-80 %). Throughout the experiment, the oat plants were examined three times to determine the number of leaves and maximum height of the plants.

Total metal contents in the soils and plants were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES). Metals were determined after grinding the soil in an agate mortar through the actions of acid using a 4:1 mixture of HNO_3 and $HClO_4$. Soil As was determined by X-ray fluorescence (XRF).

RESULTS AND DISCUSSION

Table 1 provides the pH and OM, Al, Fe, Mn and As and other heavy metal contents of the soils used in the bioassay. It may be noted that Fe and Mn levels were high in soil 3, Zn, Pb and As levels were high in the soils of the silver mine, and Cu in those of the copper mine. Dangerously high Cd levels were detected in all the soils.

In Fig. 1, the variation over the assay of maximum height and number of leaves are shown, and the differences between dry weights in different soils are presented in Table 2. These three variables may indicate a toxic effect of soil on plants [4, 5], but it is more evident in maximum height and dry weight. It may be noted, therefore, that the soils of the copper mine, where the main pollutant is Cu, cause more toxicity than those of the silver mine, where Pb is the main metal.

Despite this clear evidence of toxicity, the metal accumulating capacity of oats is obvious, as previously shown [6, 7]. Levels of Zn, Pb, Cd, Cu and Fe were high in roots as well as in the above-ground parts of the plants, and high As levels were also found in the roots of plants growing at the silver mine (Tables 3 and 4). In the case of Cu, Zn and Cd, this accumulating capacity is even greater than the maximum found by De Haro *et al.* [8] in an *Amaranthaceae* plant, a botanical family known for its metal accumulation capacity.

TABLE 1. Values of pH and OM (%) as well as Al, Fe, Mn, As and other heavy metal contents (mg/Kg) of the mine soils.

Soils	pH	OM	Al	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd	As
Silver mine												
Soil 1	6.3	9.0	34595	19605	300	2410	31.5	1215	16	2.0	9.0	239
Soil 2	5.4	2.9	30556	25228	329	1983	36	1742	14	2.3	5.4	281
Soil 3	7.2	9.7	25515	47875	2375	5095	85	3855	36	2.0	25.5	326
Copper mine												
Soil 4	5.2	4.7	39784	31081	564	133	971	126	17	2.2	2.8	35.5
Soil 5	5.7	15.7	28265	23813	825	362	2725	152	14	2.4	13.3	51.5
Control soil	5.9	0.82	5926	4914	113	12	5.7	n.d.	1.4	n.d.	n.d.	n.d.
Reference levels					-	140	36	50	35	100	1.0	-

n.d.: not detected

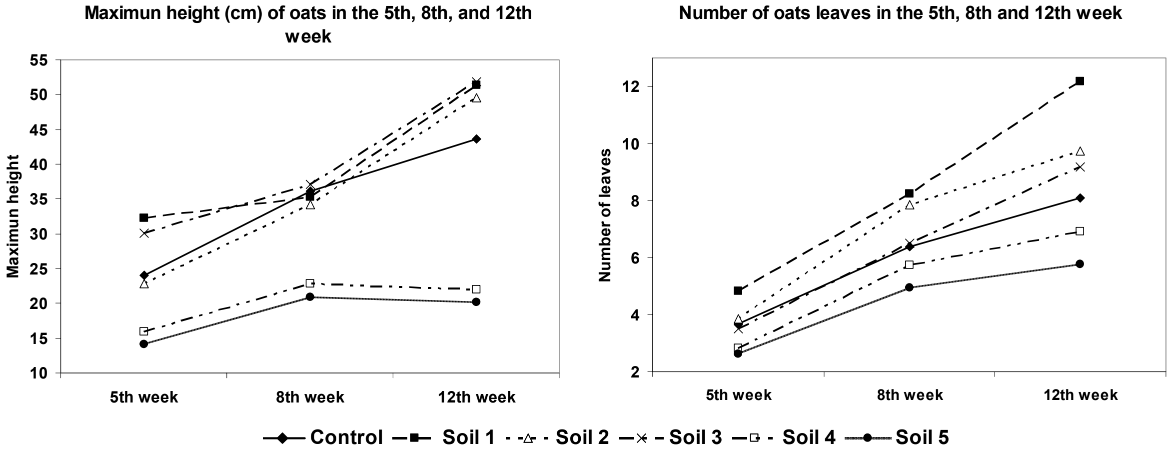

FIGURE 1 - Number of leaves and peak heights recorded for the different treatments.

TABLE 2 - Dry weight (mg) of aerial portions and roots of *Avena sativa* L.

Oat		Silver mine			Copper mine		Control soil (unpolluted)
		Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	
Above-ground weight/plant	mean	577.9	337.8	462.8	43.7	58.5	208.1
	SD	262.9	121.7	148.0	1.0	18.2	45.05
Root weight/plant	mean	120.4	43.4	97.8	20.9	19.1	54.3
	SD	51.9	14.5	10.8	1.8	9.1	4.0

TABLE 3 - Al, As and other heavy metals (means and SDs, mg/Kg) in the above-ground parts of oats grown in the two mine soils.

Soils		Al	Fe	Mn	Zn	Cu	Pb	Cd	Cr	Ni	As
Silver mine											
Soil 1	mean	51.8	133.5	277.5	728.6	9.9	51.1	5.8	11.7	5.5	0.0
	SD	27.2	68.0	144.6	532.4	6.0	44.4	4.3	6.7	3.7	0.0
Soil 2	mean	114.5	305.4	1305.9	2040.1	8.6	68.1	3.4	15.0	13.2	0.0
	SD	17.7	63.7	187.8	435.3	6.1	38.2	0.7	3.9	1.6	0.0
Soil 3	mean	60.7	178.5	443.7	369.7	8.4	57.8	2.8	12.6	6.4	0.0
	SD	46.8	72.1	63.2	40.6	6.0	32.0	0.9	5.1	1.0	0.0
Copper mine											
Soil 4	mean	344.2	260.1	1211.9	1192.4	236.9	n.d.	7.6	8.9	15.3	0.0
	SD	46.9	25.0	19.5	1404.5	56.0		2.0	0.1	1.0	0.0
Soil 5	mean	113.3	155.4	944.5	383.0	117.0	n.d.	10.8	10.3	12.1	0.0
	SD	65.8	54.6	93.5	148.5	12.7		1.3	2.3	2.6	0.0
Control Soil	mean	140.0	262.9	369.4	53.4	9.49	0.0	0.2	17.3	6.1	0.0
	SD	35.6	93.7	53.0	60.4	3.6	0.0	0.3	3.9	5.0	0.0
WHO Ref. (Foods)		-	-	< 32.5	< 45.0	< 2.9	< 1.3	< 0.23	< 30.0	< 9,8	-

n.d.: not detected

TABLE 4 - Al, As and other heavy metals (means and SDs, mg/kg) in the roots of oats grown in the two mine soils.

Soils		Fe	Mn	Al	Zn	Cu	Pb	Cd	Cr	Ni	As
Silver mine											
Soil 1	mean	2628	703.8	784	5572	102	1052	39	7.9	7.0	0.0
	SD	2212	461	532	2737	37	675	21	1.8	3.2	0.0
Soil 2	mean	12374	487	488	4894	51	1251	10	5.9	7.4	110.4
	SD	2091	91	170	3614	27	209	3	1.5	4.4	100.5
Soil 3	mean	5785	1396	1042	2418	85	2047	16	8.5	8.8	40.5
	SD	1616	529	1030	1409	24	401	4.4	2.0	0.7	
Copper mine											
Soil 4	mean	3186	401	4532	983	1521	10	21	18.3	12.4	0.0
	SD	1718	143	2600	730	134	15	0.6	4.7	0.3	0.0
Soil 5	mean	2786	846	2280	220	2201	12	44	11.6	12.8	0.0
	SD										
Control soil	mean	1473	133	750	108	46	0.0	0.0	14.2	5.3	0.0
	SD	403	29	506	53	14	0.0	0.0	21	9.1	0.0

Zn is the metal for which oats have the greatest remedial capacity. This fact is more emphasized compared with another fodder species *Lupinus albus* L., whose behaviour was studied by Pastor *et al*. [9]. This plant is widely studied because it is one of the most tolerant-to-metals legumes. In that work it was grown in acid and basic soils with increasing amounts of Zn, and its behaviour was worse than that of oats, in both above-ground part and roots. Its accumulation in leaves was also much lower.

The accumulation of toxic metals can lead us to propose the possible use of this plant as phytoremedial of contaminated sites. However, in places where the pollution caused toxicity effects very pronounced, so plant growth was not very important, as presented in the soils of the copper mine, other complementary solutions should be raised.

Conesa et al. [10] also found hitches in the re-vegetation of a polluted mine soil. Although the metal content in those soils are lower than in our study soils, the diversity of natural vegetation was low. The most compelling reason that explains this fact, independent of harsh soil and climatic conditions of the site, is the existence of extremely low soil pH, while the pH of our study soils are less acidic. The soil 3 of our study, the most polluted of the silver mine, received an amendment by the exploitation managers. The toxicity effects in this soil are less evident but the phytoaccumulation of oats decreases greatly. We also observed [11] under less adverse conditions of pH and metals than those of the mentioned authors that the metal content greatly affects the native flora in species richness, diversity for the whole community as well as major botanical families.

This accumulating capacity can be assessed, not only in terms of the possible use of this plant for phytoremediation strategies, but also of its possible impacts on humans and domestic (cows, sheep) and wild animals (rabbits, hares and partridges). In this aspect, it can be seen in Table 3 that, in most of the mine soils, the metal content in the above-ground part of oats is well above the WHO references.

Both these issues are considered to substantially compromise the chances of recovery of Mediterranean areas unaware of their soil pollution problems.

Education strategies

The restoration of ecosystems requires strategies that focus on critical targets, including measures directed at important economic sectors (such as agriculture), measures addressing key processes (climate change, biodiversity) and local measures (local development), as well as specific management methods that address a range of ecological conditions. To achieve this, farmers will need to be trained in specific ecological concepts, and economic incentives created to apply these concepts so that the resulting aerial parts and roots of crops can be used as fuel. It is, at this stage in the process, that many additional problems emerge; these problems are detailed below.

In the first place, in poor rural areas, it is difficult to avoid using these crops as a food source for livestock, as indeed other crops are used. On the other hand, even if domestic animals do not consume the crops arising from polluted soils, it is virtually impossible to avoid effects of metal bioaccumulation on other living components of the agro/ecosystem. Thirdly, political leaders and administrators need to be made aware of the problem to bear the economic costs of soil decontamination by crops as discussed above. In this context, it is essential to understand not only the elements and processes that are being introduced into ecosystems and the countryside, but also to understand the perceptions, opinions and attitudes of the persons most directly affected to successfully implement the necessary mechanisms to plan and manage the project.

Despite the fact that experts agree that soil pollution is the second leading factor to deforestation that impedes the conservation of our natural resources, today's perception of soil pollution lags behind a general awareness of the pollution of the air we breathe or the water we drink. This gap in our understanding requires the design of an environmental education program to specifically address the challenges of restoring areas of endemic poverty.

The health education involves communication of information and development of personal skills that demonstrate organizational possibilities of various forms of action aimed at achieving environmental changes, not only social or political ones, that promote health.

CONCLUSIONS

Our study reveals the good metal accumulation capacity of oats. Despite indisputable benefits for phytoremediation, however, metal uptake by this crop can pose a serious health risk to the people and cattle consuming this plant. This hazard determines a need to train rural populations in basic ecological concepts and to adopt education programs targeted at enhancing current perception of the magnitude of the soil pollution problem.

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