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BIOLOGICAL ASPECTS OF METAL WASTE RECLAMATION WITH SEWAGE SLUDGE IN POLAND

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Introduction

In the past ten years about 3000 waste-water treatment plants have been built in Poland. The result of this development has been a massive increase in overall sludge production. According to data supplied by the Ministry of Environmental Protection, 400,000 dry tons of sludge are generated every year in Poland (Koblak-Kalinska 1996). Still it is difficult to estimate the amount of sludge which is used in agriculture or for reclamation purposes. However, it can be assumed that this comes to no more than 10 percent of all sludge produced in Poland on a yearly basis. Thus it became obvious that an urgent solution to this problem was needed. Local authorities in Silesia realized in the early 90's that a demonstration was necessary to encourage the proper utilization of sludge. This was the basis for establishing the Biosolids Subpart of the Silesia Project which addressed the use of biosolids in the reclamation of mining and smelting dumps (Stuczynski et al. 1996). Metal waste sites themselves are known to contain more than 87 million tons of waste (Pistelok et al. 1995). Each year this amount increases by approximately 400,000 tons. We realized that a simple solution for stabilizing these sites would be to cover them with vegetation in order to reduce leaching of toxic elements, as well as to keep metallic fugitive dust from entering the environment. The reclamation of smelter waste sites which was carried out within the framework of the Silesia Project was a joint effort of local government, industry and international research institutions/agencies, including the US Environmental Protection Agency (EPA), the Center for Research and Control of the Environment (OBIKS), Virginia Polytechnic Institute and IUNG. One of the goals was to evaluate the possibility of adapting the rules of sludge management currently used in the United States to conditions commonly found here in industrial regions of Poland. However, the main objective of the Silesia Project was the development of guidelines concerning all aspects of sludge use for the reclamation of degraded lands and waste sites. Biological aspects related to reclamation of metal waste with the use of biosolids will be discussed in this paper.

Wasteland Reclamation in Silesia

A traditional strategy for the reclamation of wastelands and degraded lands is based on top soiling methods followed by the intensive use of fertilizers and the planting of various grass mixtures. There were successful attempts to revegetate mining waste areas through the application of only mineral fertilizers and the direct planting of grasses (Patrzalek and Strzyszcz 1980). In the end, however, these solutions were not found to be cost effective and sometimes were technically difficult. The primary limitation with topsoiling is the lack of quality soil material. Moreover, this soil material is of poor quality with respect to its content of nitrogen, phosphorous, potassium, other nutrients, organic matter and its adverse physical properties. As shown in Table 1, in average none of the sludges from the Silesia region met required standards for agricultural use. Most samples had elevated concentrations of zinc, and some also had elevated levels of lead and chromium. Therefore metal contaminated waste treatment seems to be the only potential use of such materials. Taking these arguments into account, it is reasonable to assume that sludge would be a feasible, and possibly quite effective, alternative to traditional topsoiling techniques.

Table 1 Characterization of sludges from Silesia Region*

Metal	Sludge samples	Range	Average	Standard deviation
		mg kg^{-1}		
Cd	21	3-220	25	52
Zn	21	1350-13000	3551	2734
Pb	21	260-4000	521	951
Cu	21	41-4320	655	1108
Hg	21	126-2980	367	614
Cr	21	17-14030	10221	3213
Ni	21	15-403	74	104

*unpublished OBKIS data

The main objective here is to develop and implement techniques for safe use of sludges which would meet all respective ecological, sanitary and hygienic standards (Pantuck et al. 1996). There is a general consensus that clear and concise set of procedures and guidelines such as those which are currently in use in both the United States (USEPA 1992) and Western Europe (Davis and Hall 1997; Bergs and Linder 1997) need to be developed immediately. Such regulations and guidelines must take into consideration practical aspects of sludge disposal, not just thresholds. These would be sampling methodologies of an area designated for treatment, the extent of monitoring the site after treatment, techniques for treating slopes, safe distances from surface waters, drinking water supply facilities, etc. An important goal of our studies was to asses to what extent sludge treatment would support ecosystem functioning as measured by biological activities of revegetated metal waste. Another crucial aspect was related to the assessment of metal transfer to the ecosystem which could affect the health of local fauna and also create a food chain risk.

Site description

To validate biosolid use for the reclamation of wastelands a pilot project was established in the shutdown site of a Huta Warynski smelting plant. This site contained waste from two different smelting processes - Welz and Doerschel. The Welz process takes place in long, spinning furnaces which were used to enrich low-zinc and lead ores. In this process the load mix is reduced. The zinc oxide produced in this process, together with cadmium and lead compounds, are trapped in scrubbers. The remaining waste is transferred to the waste pile. The Doerschel process takes place in the furnace which simultaneously swings and rotates, and which is used specifically for the lead smelting process. The load consists of galena, lead oxide, lead sulfate, sodium carbonate, coke and recycled iron. In this process, lead compounds are reduced into pure metallic form while cadmium is volatilized and precipitates into dust - so called cadmium concentrate. The waste generated in these processes exhibits quite different properties and toxicity. The Doerschel waste as compared to Welz on the average contains more cadmium and lead. (Table 2). The Doerschel waste is characterized by an extremely high mobility of metals as measured by water extraction as well as by high salinity.

Table 2 Total metal content in waste materials sampled before treatment

Waste material	Zinc (g kg^{-1})		Cadmium (g kg^{-1})		Lead (g kg^{-1})	
	average	range	average	range	average	range
Welz	30.9	6.9-128	0.54	0.058-2.76	7.9	2.6-16.5
Doerschel	75.1	13.0-126	2.31	0.66-3.46	23.82	7.09-40.6

Both wastes, however, become an environmental hazard through leaching and wind erosion. The revegetation of such wastes is a challenging task for reasons of phytotoxicity. Since there was a lack of data concerning this subject, we needed a better understanding of the physical and chemical processes involved in revegetation. Therefore we conducted a number of field and pot experiments. The pot and field experiments were designed to evaluate the impact of sludge and lime application rates on vegetation. In these experiments we have tested grass species and legumes regarding their adaptation to harsh environmental conditions. Our objective was to select the best performing species on the basis of low metal absorption and salinity resistance.

Feeding studies were also conducted in order to look at the eco-toxicology and food-chain risk aspect associated with the revegetation of metal-wastes in Silesia. The revegetation effort to stabilize smelter toxic waste sites was supported by studying biological activities to asses sustainability of the new ecosystems established .

Results

The monitoring of chemical properties of wastes indicates that the primary reason behind phytotoxicity of some smelter wastes lies in the high mobility of zinc and cadmium as well as in low pH and high salinity levels as expressed by sodium and sulfate concentrations. Sludge application at the rate of 300 dry tons per hectare combined with the incorporation of lime in an oxide and carbonate form at the rate of up to 1 1/2 tons and 30 tons, respectively, per hectare ensure successful revegetation. The analysis of spatial distribution of vegetative cover and waste surface chemical properties has indicated that the method is productive if the following thresholds are not exceeded: soluble Cd (55 mg kg^{-1}), Zn(1000), Na (1600 mg kg^{-1}), SO$_4^{2-}$ (20000 mg kg^{-1}) - Table 3. The pH threshold should not be lower than 6 - otherwise solubility of metals will increase dramatically, leading to phytotoxicity.

Table 3 Values characterizing chemical properties of waste tolerated by grasses grown on revegetated smelter waste

Zinc mg kg^{-1}		Cadmium mg kg^{-1}		Lead mg kg^{-1}		Soluble sodium mg kg^{-1}	Soluble sulfates mg kg^{-1}	EC mS cm^{-1}
total	soluble	total	soluble	total	soluble			
100000	1000	1700	55	11000	3.7	1600	20000	5.4

The large spatial variability of properties responsible for phytotoxicity controls the spatial variability of biomass production. In order to achieve an equally-distributed ground cover, we would suggest that the reclamation work must first be preplanned with a detailed grid-based spatial analysis of basic waste chemical properties. This allows a site-specific treatment of the most problematic areas with specially-designed rates of biosolids and lime as well as appropriate grass mixes.

Regardless of the fact that the toxicity of Welz waste was very high, the treatment used allowed the establishment of ground cover over more than 80 percent of the area tested. This means that the adaptation capabilities of selected species were considerable. At the same time, when tested on Doerschel waste the same approach failed miserably because of high concentrations of soluble metals and salinity (Table 4).

Table 4 Chemical properties of waste material sampled before (1994) and after (1995) amendment with sewage sludge and lime

Waste material	Sampling time	Soluble zinc mg kg^{-1}	Soluble cadmium mg kg^{-1}	Soluble lead mg kg^{-1}	pH	EC
Welz	Before	343	17.6	1.8	7.0	7.3
	After	279	17.7	1.1	7.2	3.5
Doerschel	Before	1670	108	5.4	5.8	16
	After	983	57.4	2.9	6.0	9.0

* values reported reflect averages of 80 samples of each material

The results of the field experiments designed to determine the factors crucial to plant growth on reclaimed waste sites could not be statistically analyzed using classical analyses of variance and averages testing. This stemmed from the fact that the variability of the waste properties was much greater than the effects of treatment. The interpolation of waste properties overlaid with graphs of biomass performance has enabled us to identify and quantify factors responsible for phytotoxicity. It was assumed that areas with at least 80 percent of ground cover did not exhibit toxicity to plants even though the total metals, the water extractable metals and the salinity were quite high (Figure 1).

The spatial variability present in the waste piles which were studied provided a unique opportunity to determine the extent of plant resistance to this adverse environment. From the results of our spatial analysis, it seems obvious that high salinity, and to a lesser extent soluble zinc and cadmium, are the most limiting factors which determine the effectiveness of revegetating these smelter waste sites with biosolids (Figure 1). However, it is also evident that these elements co-vary together and thus cannot be isolated as being singularly phytotoxic. These analyses thus enable us to conclude that the grass cultivars can adapt to the relatively harsh conditions that were seen in treated Welz material (Figure 1).

Adverse physical properties of the Doerschel material, particularly high compaction and sedimentation, also contributed to the total inhibition of plant growth. Lime and sludge at the rates used were not effective for the establishment of vegetation, although, their incorporation reduced metal solubility which will definitely decrease the potential of metal leaching from these piles (Table 4). We should emphasize that changes in pH and cadmium and zinc solubility in both Doerschel and Welz material - as affected by sludge and lime application - were smaller than expected. Evidently, liming was not effective for pH and metal solubility control with these materials - most likely due to limited solubility and/or occlusion with iron or other metal oxides that were present in solutions at very high levels. Our laboratory experiments demonstrated that heavy rates of calcium carbonate did not result in substantial increases of pH. Nor did they result in a reduction of cadmium and zinc solubility. On the other hand, calcium oxide reduced metal mobility to ppb levels although this effect may be temporary since the calcium oxide buffering system can change with time into calcium carbonate via CO_2 absorption. This seems very likely since the addition of calcium oxide along with calcium carbonate to smelter plots did not affect the initial pH or metal solubility to any great extent after the first year of sludge application.

The materials similar to Doerschel waste may be treated with a less toxic waste cap as done in our experimental fields. A fifteen-centimeter cap of waste lime which subsequently received 300 tons of sludge created growing conditions for a tolerant grass seed mix. This type of treatment resulted in a 80-90 percent ground cover success rate with little of metal toxicity in the vegetation. On-site soil evaluation indicated that the roots penetrated to the lime/waste interface, but not more than two centimeters into the underlying toxic material. Furthermore, it was evident that even a minimal treatment enables vegetation to sustain itself through summer droughts. With time it can be noted that a number of perennial herbaceous and woody species invade the plots from the surrounding area. This supports the statement that the chemistry of toxic metal waste materials has thus been sufficiently stabilized by the use of lime and sludge in order to support long term plant growth.

Selection of grass cultivars

The data shown in Tables 5 and 6 characterizes the metal uptake by different grass cultivars grown on smelter waste in a pot study. The first set of pot-study experiments depicts metal uptake in grasses grown on low-salinity smelter waste while the second set contains data characterizing metal uptake in grass cultivars grown on high-salinity smelter waste (Welz material).

Table 5 Grass variety pot study on low salinity Welz material - yields of grass cultivars and concentration of heavy metals

Cultivars		Yield (g/pot)	Zn mg kg^{-1}	Pb mg kg^{-1}	Cd mg kg^{-1}
Argona	*Lolium perenne*	1.99	587.27	50.00	28.53
Solen	*Lolium perenne*	2.10	233.70	86.85	16.85
Koga	*Lolium multiflorum*	1.76	197.60	52.20	38.82
Mega	*Lolium x boucheanum Kunth*	2.30	339.27	49.63	20.53
SZD	*Festuca arundinacea*	1.36	91.35	23.30	20.10
Trzcinnik	*Calamagrostis sp.*	1.47	216.03	23.37	27.43
Alicja	*Poa pratensis*	1.74	266.37	101.90	22.18
Atra	*Festuca rubra*	0.92	639.33	48.33	51.40
Igeka	*Agrostis vilgaris*	0.86	113.40	46.70	67.40
Nakielska	*Festuca rubra*	0.22	97.73	59.83	36.73
Sawa	*Festuca heterophylla*	0.42	638.33	78.93	46.20

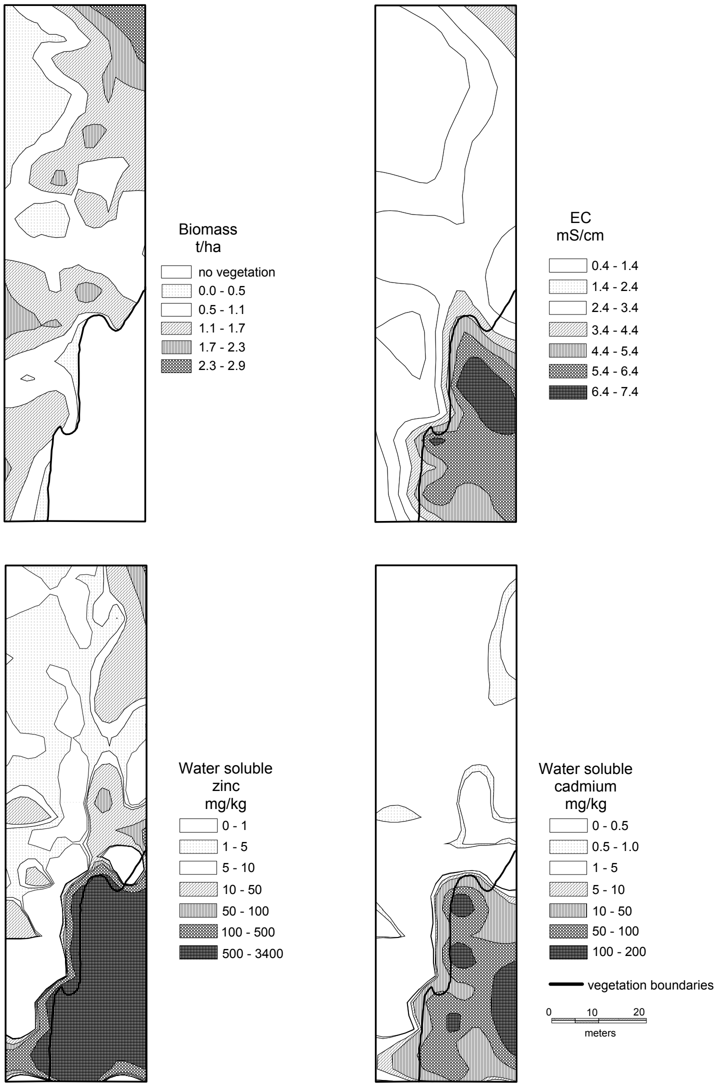

Figure 1 Standing biomass and WELZ waste chemical properties over the experimental area

As we can see from the demonstrated data, cultivars have different abilities to accumulate metals.
A number of the twenty two grass cultivars which we tested in pot experiments seemed to be useful for revegetation purposes and demonstrated different degrees of adaptation to chemical stress (Table 7).

It is also worth noting that the same cultivars grown in the field may react differently to overall environmental conditions than they would in a pot study. This was reflected in metal-uptake performance. Table 7 contains data from the field study -- the results reported here are the part characterizing the chemical composition of cultivars grown on Welz smelter waste which was amended with 300 tons of sewage sludge per hectare.
Our analytical data from the pot and field experiments shows that there are statistically significant differences in cadmium uptake among grass cultivars. These differences, have practical meaning and help selection of grass species reducing the risk of metal accumulation in wildlife.

Table 6 Grass variety trial on high salinity Welz material - yields of grass cultivars and concentration of heavy metals

Cultivars	Scientific name	Yields (g/pot)	Zn mg kg^{-1}	Pb mg kg^{-1}	Cd mg kg^{-1}
Argona	*Lolium perenne*	1.63	529	271	21.07
Solen	*Lolium perenne*	2.33	438	155	25.17
Koga	*Lolium multiflorum*	1.86	567	131	36.47
Maguntaja	*Dactylis glomerata*	0.75	239	11	9.67
Mega	*Lolium x boucheanum Kunth*	1.92	320	155	14.53
SZD	*Festuca arundinacea*	1.11	260	40	40.60
Trzcinnik	*Calamagrostis sp.*	0.85	516	64	24.77

Table 7 Cadmium zinc and lead content in grass species grown on Welz waste - field study

Cultivar	Scientific name	Cd mg kg^{-1}	Zn	Pb
Alicja	*Poa pratensis*	4.69	239	46.4
Areta	*Festuca rubra*	2.82	195	25.5
Argona	*Lolium perenne*	3.04	249	46.2
Ascherson	*Dactylis aschersoniana*	2.38	175	-
Atra	*Festuca rubra*	2.27	161	31.7
Brudzyńska	*Festuca arundinacea*	4.37	303	48.9
Festulolium	*Festulolium*	1.60	167	21.3
Igeka	*Agrostis vulgaris*	2.40	260	26.7
Kita	*Agrostis alba*	1.79	206	33.8
Leo	*Festuca ovina*	3.62	279	33.6
Niga	*Lolium perenne*	3.42	207	24.3
Nimba	*Festuca rubra*	2.08	220	39.0
Nina	*Festuca canina*	2.79	214	29.4
Nira	*Lolium perenne*	3.31	209	37.6
Niwa	*Agrostis vulgaris*	3.24	248	30.1
Reda	*Festuca rubra*	3.01	213	29.2
SZD 492	*Festuca arundinacea*	2.08	188	24.7
Salty alkaligrass	*Puccinelia distans*	2.73	168	34.3
Sawa	*Festuca heterophylla*	3.75	182	29.8
Sima	*Festuca ovina*	3.82	309	42.4
Terros	*Festuca arundinacea*	2.70	199	24.1
Smialek	*Deschampsia ceapitosa*	3.17	211	29.7

None of the studied cultivars showed an iron deficiency, even though the waste on which they were cultivated contained extremely high levels of zinc. This can be explained by the fact that the smelter waste reclaimed with sludge contained large amounts of iron -- it is very likely that there is an interaction between organic matter present in sludge and iron oxides. This interaction forms a specific sorption for metals.

Results of both field and pot studies allow us to propose a mixture of the most acid/salt-tolerant species which were selected from the list shown in Table 8. Such a selection of cultivars may be needed for different types of waste.

Table 8 Resistance of grass species and cultivars to metals and salinity

Cultivars	Scientific name	Tolerance to metals	Tolerance to salinity
Solen	*Lolium perenne* (Solen)	+++*	+++
Argona	*Lolium perenne* (Argona)	+++	+++
Telga	*Lolium multiflorum* (Telga)	++	++
Koga	*Lolium multiflorum* (Koga)	++	++
Mega	*Lolium x boucheanum Kunth.* (Mega)	++	++
Trzcinnik	*Calamagrostis* (natural ecotype)	++	+
Alicja	*Poa pratensis* (Alicja)	+++	-
Atra	*Festuca rubra* (Atra)	+	-
SZD 492	*Festuca arundinacea* (SZD 492)	++	+
Sima	*Festuca ovina* (Sima)	++	-
Igeka	*Agrostis vulgaris*	+++	++

* degree of tolerance

Biological activities of revegetated waste

The revegetation effort to stabilize smelter toxic waste sites was supported by studying biological activities to asses sustainability of the new ecosystems established. Measurements shown substantial activity of most enzymes - Table 9. However, significant spatial variability was observed in this system similar to that of biomass and other indicators shown on Figure 1. The spatial structure was highly correlated to the distribution of organic matter. This indicates that the biological activity is driven by the distribution of sludge applied and incorporated with the surface of the waste material.

Table 9 Enzyme activities of reclaimed smelter waste (Welz Material)

Activity	Unit	Minimum	Maximum	Mean	Geom. Mean
Phosphatase acidic	(µg p-nitrophenyl g^{-1})	27,78	210,18	70,020	62,878
Phosphatase alkaline	(µg p-nitrophenyl g^{-1})	12,30	228,07	77,387	67,250
Dehydrogenase	µg TPF g^{-1}	7,31	999,03	279,591	196,229
Arylsulfatase	(µg p-nitrophenyl g^{-1})	15,93	265,91	71,008	62,357
Urease	mg N-NH$_4$ kg^{-1}	18,09	357,67	111,873	97,630
Respiration	µg C-CO$_2$ g^{-1} 24h^{-1}	4,70	52,25	22,482	20,759
Fungal respiration	µg C-CO$_2$ g^{-1} 24h^{-1}	40,95	177,15	87,250	81,649
Bacterial respiration	µg C-CO$_2$ g^{-1} 24h^{-1}	11,25	207,00	78,288	69,577

As reflected by multivariate regression models very little toxicity can be assigned to heavy metals present in the soil ecosystem - Table 10. It seems that cadmium has some adverse effect on biological activity, while zinc and lead do not demonstrate toxic impact on these activities to any greater extent, as reflected by multivariate regression models developed.

Measurements of enzyme activities in reclaimed metal waste produces similar results to that of usable soils. This indicates that the reclamation methods used by amending toxic metal materials with sewage sludge and lime can be an effective way to establish new, fully-functioning ecosystems that support plant growth.

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Table 10 Model fitting results for enzyme activities - Welz material reclaimed with sewage sludge

Enzyme	Independent variable	Coefficient	R^2	Sig.level
Phosphatase acidic	Constant	11.176	0.81	0.054
	Available P	1.007		0.019
	Water soluble Na	2.599		0.000
	Water soluble Cd	-2.063		0.000
	OM	3.328		0.000
Phosphatase alkaline	Constant	5.103	0.76	0.484
	Available K	3.282		0.021
	Water soluble Na	3.069		0.000
	Water soluble Cd	-17.773		0.000
	OM	3.457		0.000
Arylsulfatase	Constant	6.638	0.83	0.290
	Available P	2.626		0.000
	Water soluble Na	2.822		0.000
	Water soluble Cd	-1.949		0.000
	OM	2.560		0.003
Urease	Constant	21.551	0.55	0.154
	Water soluble Na	3.262		0.003
	Water soluble Zn	-0.758		0.004
	OM	6.609		0.000
Respiration	Constant	-66.056	0.64	0.000
	pHKCl	9.808		0.000
	EC	3.603		0.002
	OM	1.030		0.000

Feeding trial

A feeding study was conducted with young cattle to measure the extent of metal transfer from Pb, Cd and Zn contaminated hay which was harvested from smelter waste reclaimed with lime and sewage sludge (Table 11). In order to measure the Cd transfer from contaminated crops into the food chain, young cattle were fed with the hay harvested from experimental plots established in Silesia, versus clean hay as a control (Stuczynski and Chaney 1997). There were two other groups: (i) fed with the control hay spiked with Cd salt in the amount needed to match Cd content of hay from Silesia, and (ii) fed with hay amended with Cd and Zn to bring the Zn:Cd ratio to that of hay contaminated by natural uptake from the high metal soil.

The data in Table 11 indicate that the Pb and Cd levels found in hay harvested from reclaimed zinc and lead smelter waste greatly exceeded current thresholds values by 20 and 12 fold, respectively.

Table 11 Metal content in feedstuff used in experiment (mg kg^{-1} dried matter)

Treatment	Pb	Cd	Zn	Fe	Cu
Control	2.60	0.38	25.34	711	7.50
Contaminated hay	200	6.64	298.00	1642	21.40
Concentrate	3.50	0.44	41.80	360	16.40
Threshold value*	10.00	0.50	50		50

* threshold value accepted in Poland

However, none of treatments studied, including hay amended with mineral forms of Cd and Cd+Zn adversely affected the growth of the animals in any period of the experiment (Table 12). Moreover calves monitored did not show any visible symptoms of health disorder. Forage crops grown on sludge amended metal contaminated land are high in metals but their bioavailability to cattle is greatly limited. There was no significant accumulation of Pb and

Cd observed in muscles. The absorption of Cd by calves was controlled by Zn present in the diet. The response of organs to feed amendments with Cd and Cd+Zn in the form of salt demonstrates the reduced risk of Cd accumulation in the presence of Zn. We have proven that crops grown on remediated soils may be fed to livestock safely without affecting food safety. However, additional studies are needed to demonstrate the extent of metal movement into organs of other mammals under conditions similar to that of the conducted experiment.

As mentioned before no excessive transfer of Pb and Cd to muscles and bones was observed. The maximum permissible levels (MPL) accepted in Poland for Pb and Cd in meat are 0.3 and 0.1 mg kg^{-1}, respectively. The concentration of Pb found in muscles of calves fed with contaminated hay grown on smelter soil was 30 times smaller than MPL, while accumulation of Cd was two orders of magnitude smaller as compared to MPL. Moreover, there was no accumulation of muscle Cd in the group fed with $CdCl_2$ amended hay, which suggests that the level of Cd added can be considered as sub-toxic.

Cadmium present in naturally contaminated hay, accumulates also in pancreas, spleen, brain and lungs but to much lesser extent than in kidneys and liver. Hay amendment with $CdCl_2$ dramatically enhances Cd accumulation in these organs, however the addition of zinc reduces this transfer. It is remarkable that Cd added to the hay in easily available salt form moves into the heart but zinc limits its absorption (Table 12).

Elevated Pb present in hay transfers to pancreas, brain, heart, spleen and lungs. The question arises if longer term exposure to Pb would have any effect on functions of these organs.

The results reported clearly indicate that crop contamination with Pb, Cd and Zn by natural uptake of these elements has significantly different effects on their transfer to animal tissues than from feedstuff amended with metal salts. This provides strong evidence that studies utilizing metal salt amendments to feed to evaluate the metal accumulation in the animal body can not be accepted as a valid way for deciding the respective thresholds and assessing food safety. There are additional convincing arguments collected that the interaction between Zn and Cd plays a crucial role in controlling the movement of Cd into the food chain. It is evident from these studies that forage crops grown on Zn, Cd and Pb contaminated sites reclaimed using lime and biosolids do not pose any particular risk for wildlife and food safety, regardless to the fact that current thresholds for Pb, Cd and Zn in forage may be exceeded. It seems necessary that the existing evaluation criteria for metals in animal feed should be revised.

Table 12 Metal contents in different tissues of experimental cattle (mg kg^{-1} fresh matter)

Treatment	Pb	Cd	Zn	Fe	Cu
Muscles					
Control	0.01a	0.0010a	27.54a	7.48ab	0.29a
Contaminated hay	0.01a	0.0012a	29.05a	5.368a	0.34a
Cd amended hay	0.01a	0.0016a	25.60a	9.416b	0.48b
Cd+Zn amended hay	0.01a	0.0014a	25.25a	5.368a	0.33a
Liver					
Control	0.093a	0.034a	41.82b	44.31a	37.92b
Contaminated hay	2.174b	0.134b	39.92ab	31.92a	27.17a
Cd amended hay	0.071a	0.648c	36.08a	35.70a	29.67a
Cd+Zn amended hay	0.039a	0.226b	38.54ab	39.27a	30.33a
Kidneys					
Control	0.14a	0.17a	28.76a	36.75a	3.55bc
Contaminated hay	4.06b	0.53b	29.19a	49.56c	2.89a
Cd amended hay	0.21a	2.10d	29.52a	45.57bc	3.48bc
Cd+Zn amended hay	0.12a	0.776c	27.55a	40.95ab	3.23ab
Brain					
Control	0.026a	0.0010a	14.59a	18.32a	1.95b
Contaminated hay	0.280b	0.0058b	15.65a	20.65a	1.62a
Cd amended hay	0.032a	0.0072b	15.65a	16.24a	1.59a
Cd+Zn amended hay	0.030a	0.0054b	16.87a	19.72a	1.76a
Heart					
Control	0.010a	0.0010a	18.24a	48.05b	3.12b
Contaminated hay	0.050b	0.0016a	18.16a	46.81b	3.18b
Cd amended hay	0.016a	0.0056b	16.87a	40.61a	2.28a
Cd+Zn amended hay	0.010a	0.0010a	17.52a	39.37a	2.40a
Spleen					
Control	0.010a	0.0024a	22.87a	100.10b	0.57b
Contaminated hay	0.220b	0.0046b	22.34a	98.80b	0.49a
Cd amended hay	0.020a	0.0358d	22.26a	75.33a	0.56b
Cd+Zn amended hay	0.0120a	0.0112c	22.95a	110.00b	0.56b
Lungs					
Control	0.010a	0.0024a	19.68a	62.62a	0.90b
Contaminated hay	0.170c	0.0148b	19.76a	61.69a	0.76a
Cd amended hay	0.020b	0.0180b	20.59a	56.42a	0.89ab
Cd+Zn amended hay	0.024b	0.0058a	19.07a	53.32a	0.82ab

Explanation: abc - values with the same index are not statistically different

Conclusion

It seems that the only valid solution for the intelligent management of sewage sludge in such regions would be to use them for the stabilization and revegetation of industrial waste lands. The results of our research indicate that sewage sludges can be successfully used for the reclamation of toxic smelter waste as an alternative to traditional methods such as topsoiling. High concentrations of metals in their soluble form are only of secondary importance because their mobility can be reduced by appropriate forms and doses of lime.

For waste characterized by medium salinity such as Welz waste the recommended rate of sludge should not be higher than 300 dry tons per hectare under average conditions. Waste which demonstrates higher salinity, such as Doerschel waste, must be treated differently. An integral part of a biosolid reclamation project is the selection of grass species and cultivars that are resistant to toxicity. The appropriate selection creates conditions for good coverage of an area and limits the movement of toxic elements into the terrestrial ecosystem. The metal content in the biomass of selected species also inhibits the impact of metals on the health conditions of organisms/animals returning to reclaimed areas.

Studies on biological activities indicate that the reclamation methods used by amending toxic metal materials with sewage sludge and lime can be an effective way to establish new, fully-functioning ecosystems that support plant growth. It is noteworthy that a number of other countries such as the Ukraine, Hungary and South Africa have shown interest in biosolid applications which follow the approach presented. This could be taken as an optimistic preview of what is to come, or at the least, a step in the right direction when considering the environmental and waste-management problems now faced by countries in transition.

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