Persistence of smelter wasteland phytoremediation – lessons from long term field testing

IUNG Institute of Soil Science and Plant Cultivation State Research Institute

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Bratislava, Contaminated Sites 2013

Phytostabilisation (aided)

Still questions to answer:

how permanent?

are there universal treatments?

comparisons under similar conditions

new combinations to enhance stabilization

full assessment of effects on range of properties and soil functions or induced deficiencies

GREENLAND

BOKU INRA CSIC LULEÅ UNIVERSITY OF TECHNOLOGY INERIS University of Brighton

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY Freistaat SACHSEN universiteit hasselt IUNG SLU

TEN ATON high technology CNRS INNOVEOX

SEVENTH FRAMEWORK PROGRAMME
THEME [KBBE.2010.3.5-01]
[Biotechnology for the environment - Soil and water treatment and bioremediation - Call: FP7-KBBE-2010-4]

www.greenland-project.eu

Project acronym: GREENLAND

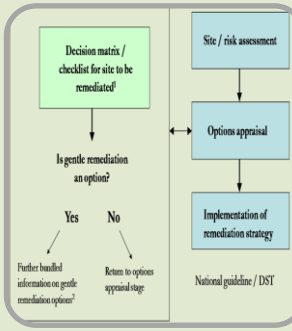
Project full title: " Gentle remediation of trace element contaminated land "

WP1:
Sustainable management adapted to TE contaminated soils and deployment of GRO at field scale

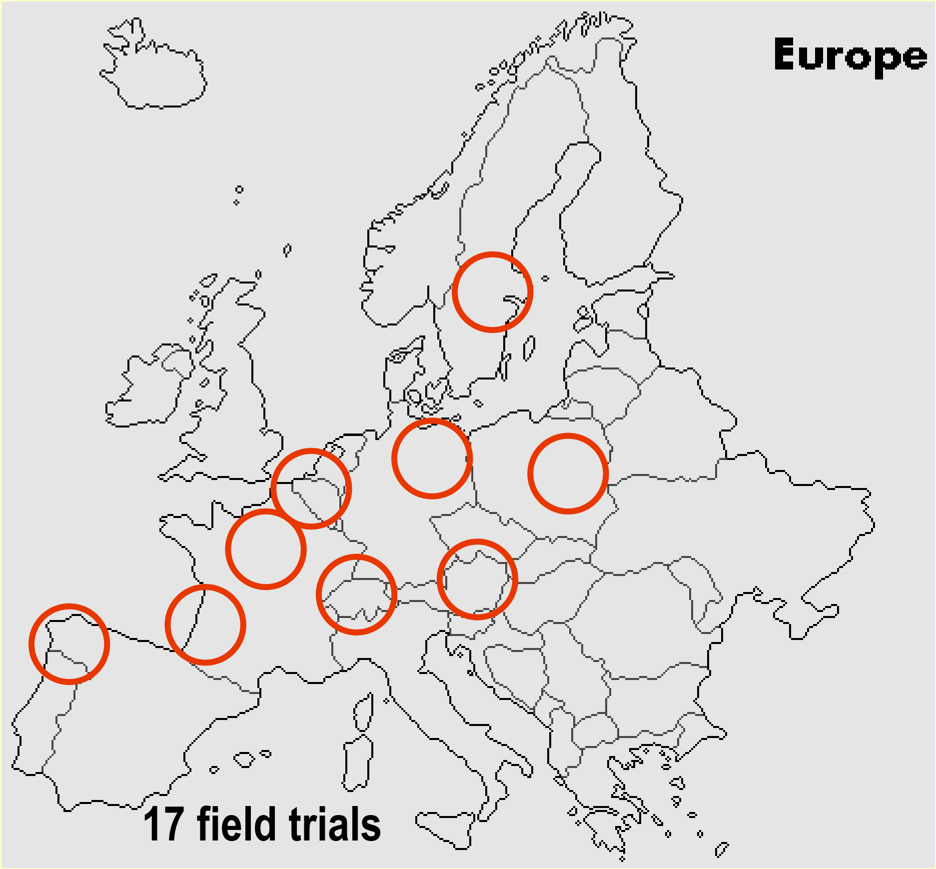
WP2:
Valorisation of plant biomass produced on TE contaminated sites

WP3:
Harmonization of methods to assess the bioavailability of TE and development of a tool set to monitor the sustainability of GRO

WP4:
Improving GRO through plant selection and modifications in soil TE bioavailability



WP5:
Appraisal of current GRO practice, and development of implementation guidance and decision support frameworks



A EU network for what?

- climatic conditions
- soil types
- contaminants
- re-use for non-food crops
- recycling of organic waste products

Main objectives

To obtain sustainable ecosystems, without or minimized pollutant linkages/risks, producing (non-food) crops for plant-based feedstock (local market), and promoting ecosystem services (positive Life cycle analysis)

Main outcome

to promote Bio-Economy and gain environmental, health and societal benefits

Ecosystem services

Biomass production C sequestration minimal use or substitution of nonrenewable inputs

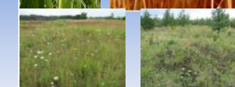
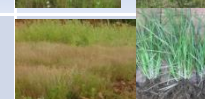
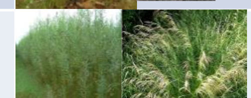
Soil biodiversity, promote animal communities, Habitat, connexion

Storing, filtering and transforming nutrients, substances and water

GREENLAND

Gentle remediation options (GRO) for trace element-contaminated soils (TECS) implemented at field scale in the Greenland network

GREENLAND

Contaminants	Countries	Years	Options	Plants
As Pb Cd Zn		1-16	In situ stabilisation/phytoexclusion	
Pb Cd Zn		14-16	In situ stabilisation/phytoexclusion	
Cu		1-2	In situ stabilisation/phytoexclusion	
Cd Zn		1	Aided phytostabilisation	
Cu		1-6	Aided phytostabilisation	
Cd Zn		5	Phytoextraction	
As Pb Cd Zn		6-18	Phytoextraction	
Cd Zn		4-6	Phytoextraction	
Cu		2-5	Aided phytoextraction	

SRC: poplars  willows 

Perennial grasses: miscanthus  vetiver 

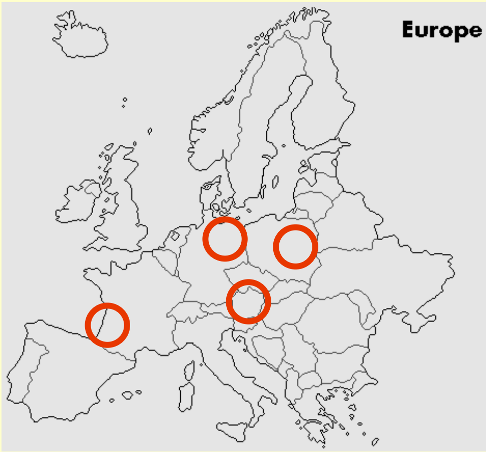
Agrostis sp  Descampsia cespitosa 

Annual crops: rape  tobacco 

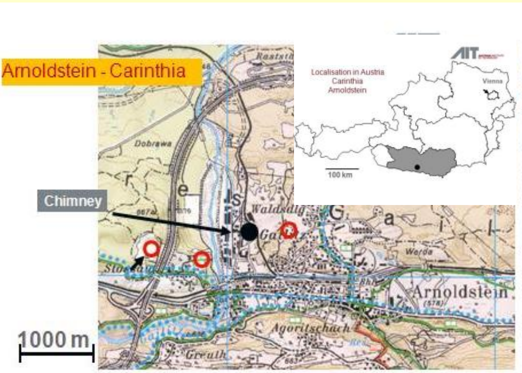
wheat  sunflower 

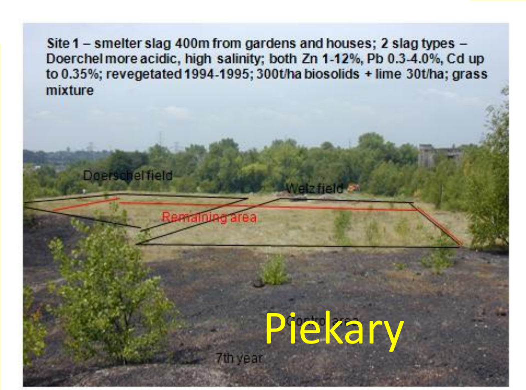
barley maize 

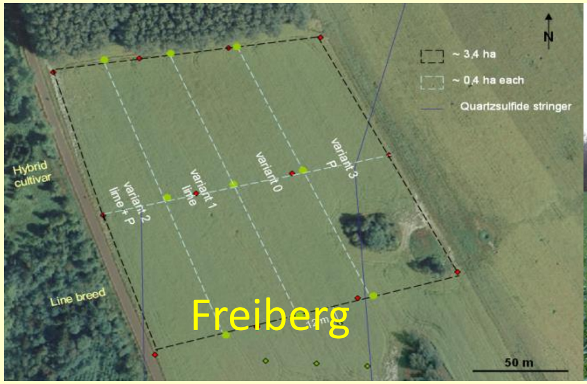
In situ stabilisation – phytoexclusion *(few/no effects of plants on contaminant (bio)availability in the root zone; main drivers: soil conditioners and cultural practices)*



	INRA	AIT	LfULG	IUNG
	Biogeco	**Arnoldstein**	**Freiberg**	**Piekary**
	Cu	As, Pb, Cd, Zn	As, Pb, Cd, Zn	Pb, Cd, Zn
	3 m² plots	2 km² (500 m²)	5 – 7 ha	10 ha
Soil conditioners	1 - 6 yr		1 – 5 yr	14 - 16
alkaline materials	Linz-Donawitz slags	Gravel sludge	7ha – 5 yr - grasses Marl lime (ML)	by-product limestone
organic matter	compost (OM)			Municipal Biosolids (MB)
Fe/Mn oxides	zerovalent Fe grit (Z)	Fe-bearing material (Siderite)		
combined amendments	OMDL, OMZ		5ha – 1 yr MLP +R,B, W	MBBL
Phosphates			Superphosphates P 40 ; R, B, W	
Plants	Grasses	Maize, barley	Grasses, Rape, Barley, Wheat	Grasses



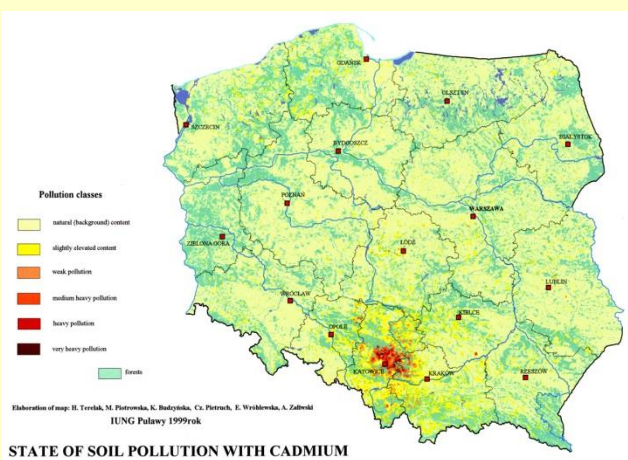




Background

- In 1992 – 1993, the health-risk assessment for the area of former Katowice Province was conducted in cooperation with the US Environmental Protection Agency.
- Smelter waste sites were found to have a significant effect on nearby populations through water and wind erosion.
- Toxic smelter waste sites are known to contain more than 87 million tons of waste. Each year this amount was increasing by approximately 400,000 tons.
- At the same time disposal of sludge from municipal wastewater treatment plants was one of the identified subjects.

Silesia

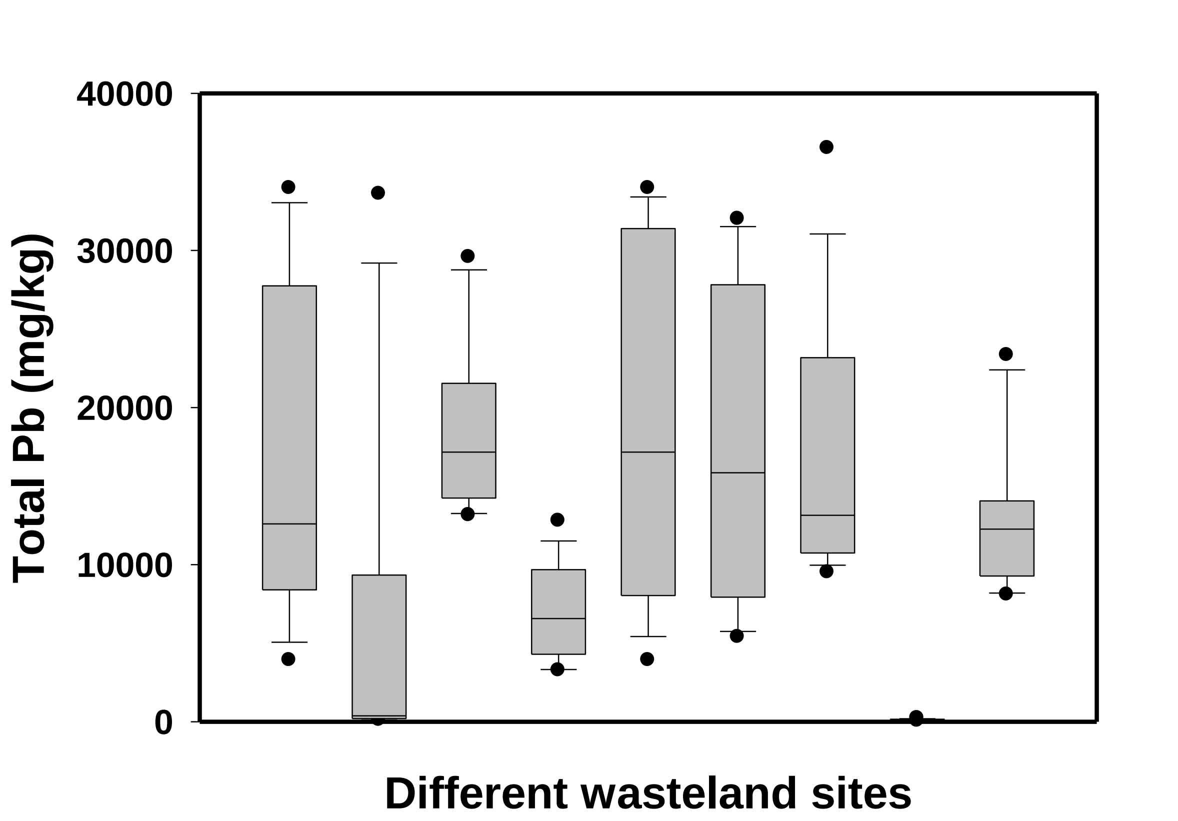


Objectives of the Silesia project

- To develop a simple solution for stabilizing toxic smelter and coal waste sites trough covering them with vegetation in order to reduce leaching of toxic elements, and the amount of metallic fugitive dust.
- To study mechanisms controlling immobilization of metals by sludge and lime treatment.
- To characterize metal foodchain risk associated with sites reclaimed with sewage sludge.
- To develop guidelines concerning all aspects of sludge utilization for the reclamation of degraded lands and waste sites.

Involved: USEPA, USDA Beltsville, Virgina Polytechnic Institute, OBIKS, local government

Smelter waste sites in Silesia



High variability of waste properties within one site and between sites

Waste site – Piekary

High metal content

Low water retention

Low content of macronutrients

High salinity

Doerschel waste acidic

Total metal concentration [g/kg] in waste materials sampled before treatment

Waste material	*Zinc*		*Cadmium*		*Lead*	
	average	range	average	range	average	range
Welz	30,9	6,9 – 128	0,54	0,06 – 2,76	7,9	2,6 – 16,5
Doerschel	75,1	13,0 - 126	2,31	0,66 – 3,46	23,8	7,1 – 40,6

Steps of the approach

Site characterization → **Treatment testing** → **Site reclamation** → **Site monitoring**

Treatment selection

-**Testing grass cultivars**

(*Festuca rubra, Festuca arund., Festuca ovina, Lollium p, Poa prat., Agrostis sp*,

naturally occuring species (*Deschampia caespitosa*)

Finally selected:
Festuca rubra L. cv. Atra,
Poa pratensis L. cv. Alicja,
Festuca arundinacea Schreb. cv. SZD,
Festuca ovina L. cv. Sima

Methodology of field demonstration study

- Pilot project was established at the former Warynski smelting plant, containing two types of toxic waste characterized by extremely high mobility of metals and salinity.
- Demonstration plots of 0.3 – 0.4 hectare were treated with sludge at the rate of 300 t /ha and up to 50t of limestone ($CaO+CaCO_3$)
- Reclaimed sites were monitored for 15 years to characterise mobility of metals and biological activities of the „top soil".

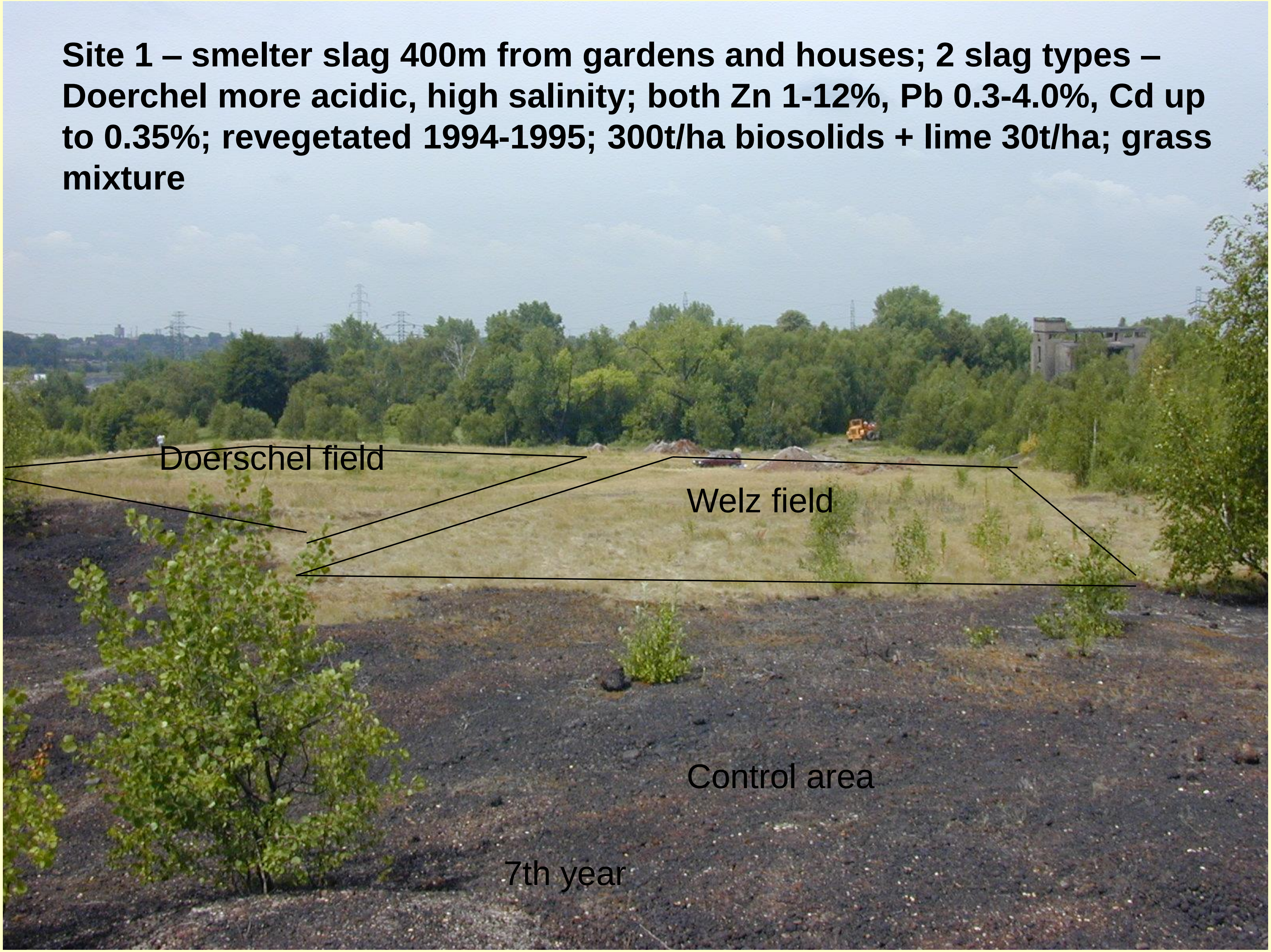
Both fields

Biosolids application → Lime application → Chisel plow → Grass mixture seeding

Doerschel field

→ Waste lime 30 cm cap → Biosolids → Grass mixture seeding

Site 1 – smelter slag 400m from gardens and houses; 2 slag types – Doerchel more acidic, high salinity; both Zn 1-12%, Pb 0.3-4.0%, Cd up to 0.35%; revegetated 1994-1995; 300t/ha biosolids + lime 30t/ha; grass mixture

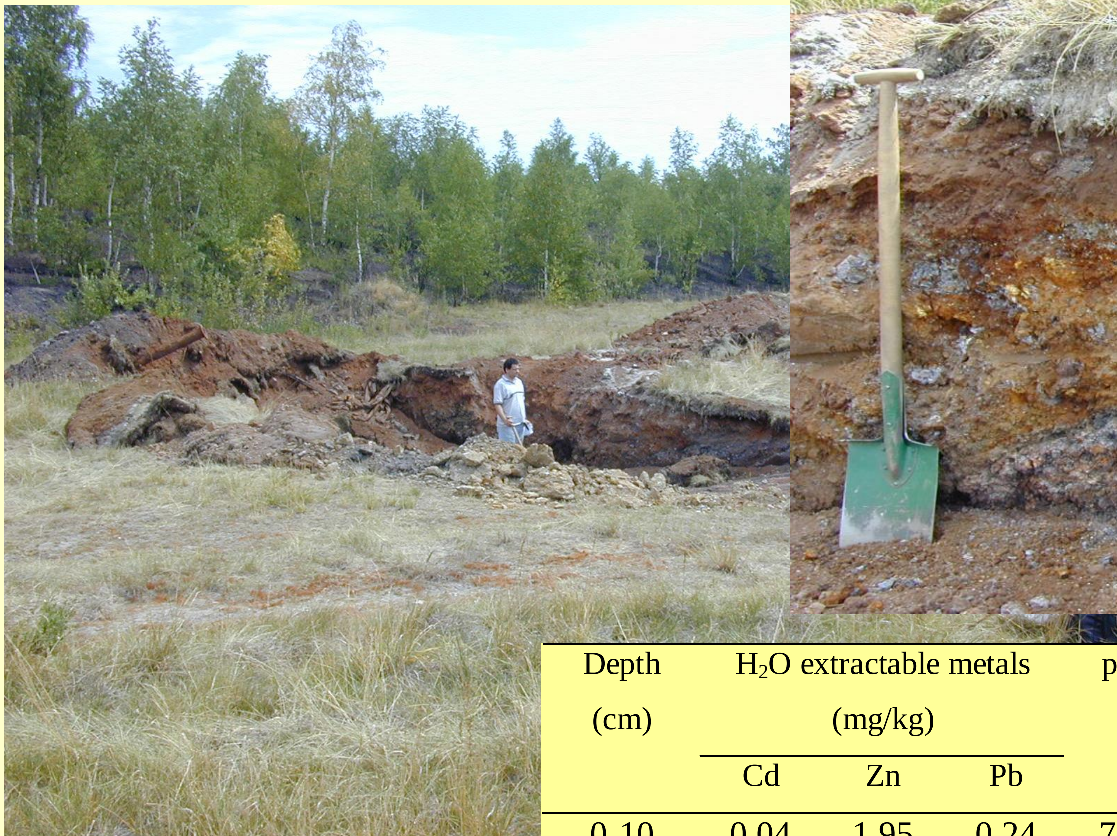



First year


7th year


Third year
6 3'98

Summer 2000 – profile of Doerschel waste capped with lime and treated with sludge in 1995



Depth (cm)	H_2O extractable metals (mg/kg)			pH	OM(%)	EC (mS/cm)	P_2O_5 (mg/100g)	Yield(g/wazon)
	Cd	Zn	Pb					
0-10	0,04	1,95	0,24	7,7	14,3	0,48	18,1	0,80
10-20	0,23	15,7	0,35	6,7	11,0	1,18	0,7	0,11
20-50	0,97	135,1	3,24	4,5	10,5	2,17	0,7	0,05
Behind treatment area	0,06	0,41	0,07	7,4	13,1	0,61	2,7	0,29

Site monitoring

Parameters analazed in samples collected in a grid:

-Water extractable metals

-Ca-chloride extractable metals

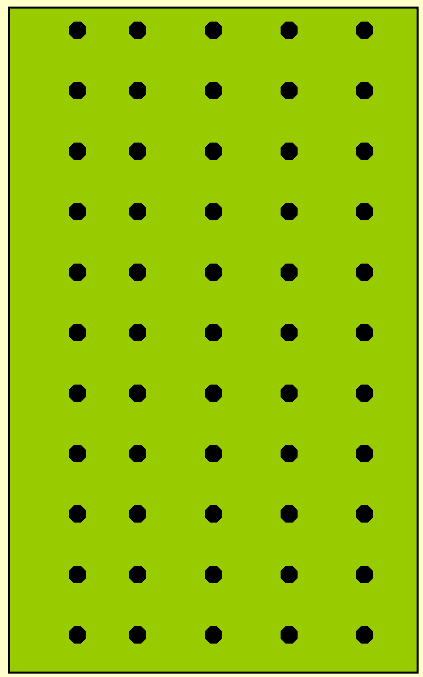
-pH, EC

-OM

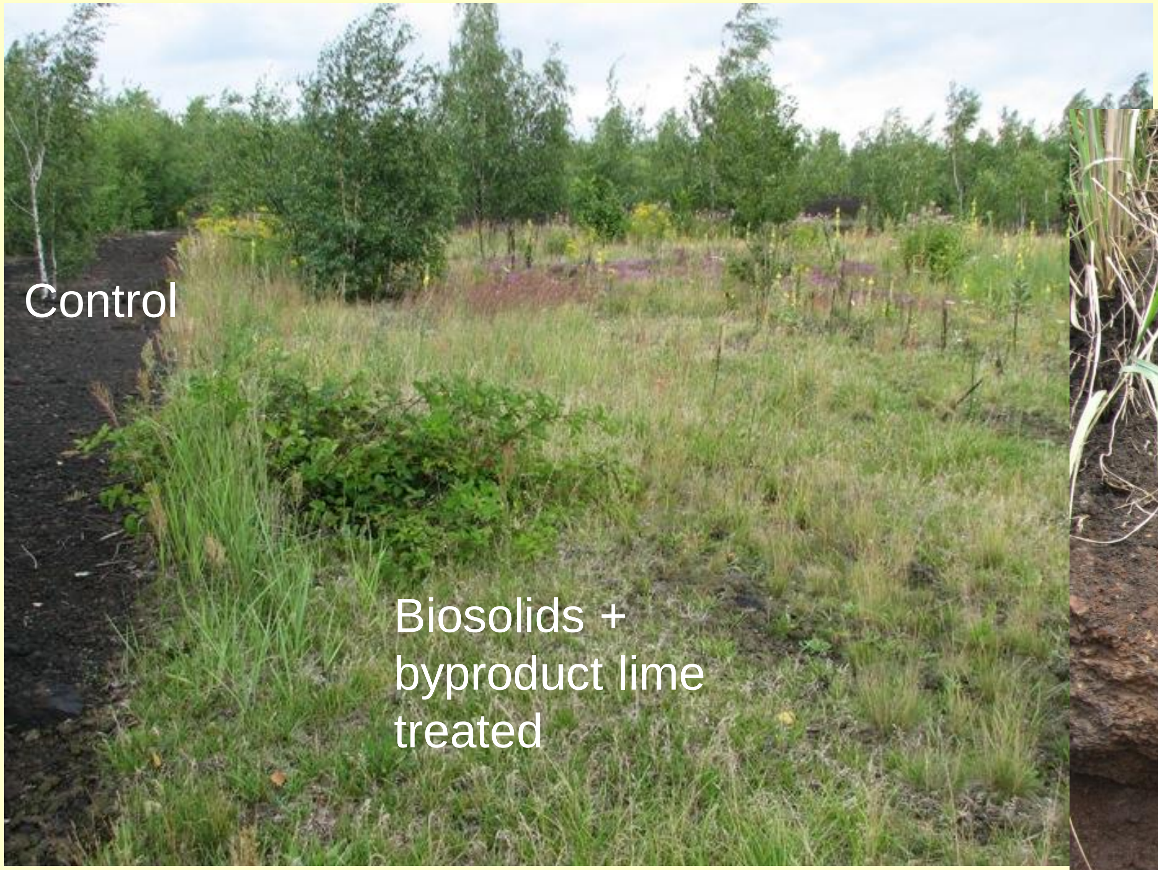
-KCl extractable N

-Enzymes, respiration

-Plant biomass, composition



Site I 17-year after remediation



Historical data:

Metals solubility, pH, mineral nitrogen, plant yield and metals, microbial activity (respiration, enzymes)

Sampling in a grid 10mx10m

Time series: 1995, 1996, 1997, 1998, 1999, 2000, 2003, 2010

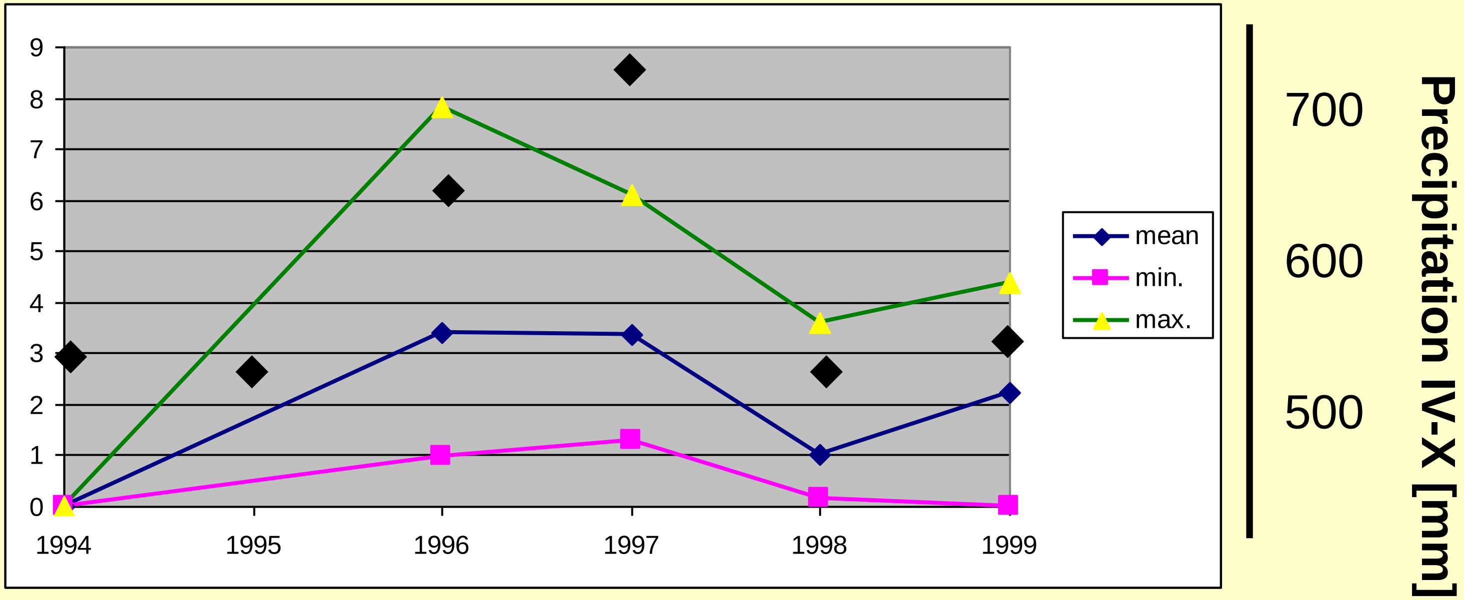
GREENLAND measurements:

-Metals solubility (Ca-chloride, H2O, NH4-nitrate, Na-nitrate), pH, OM, carbonates, EC, avail. P, K, Mg

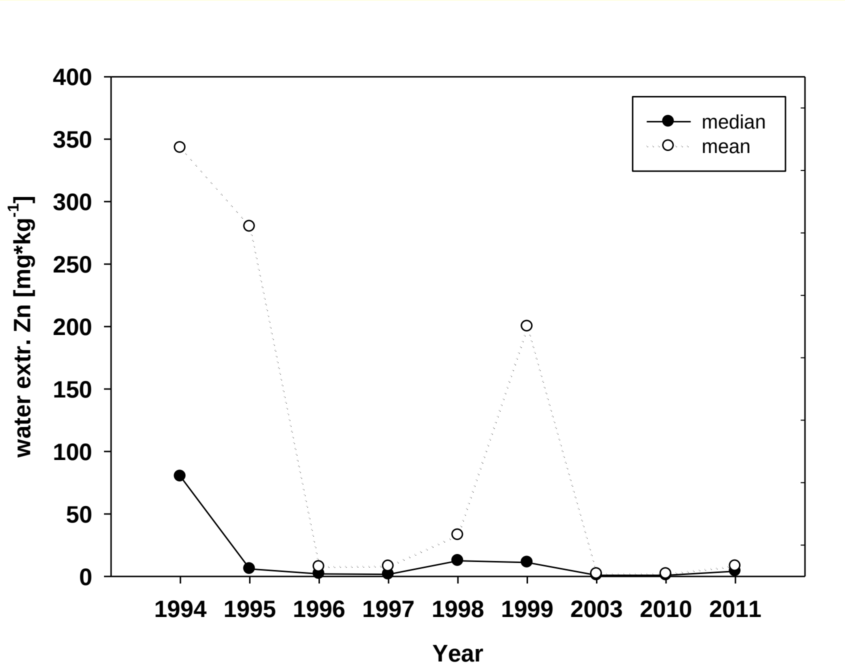
-Microbial parameters (enzymes, number of bacteria, fungi, actinomycetes, bacteria types)

-Plant cover (metal content, species frequency, initial species that survived)

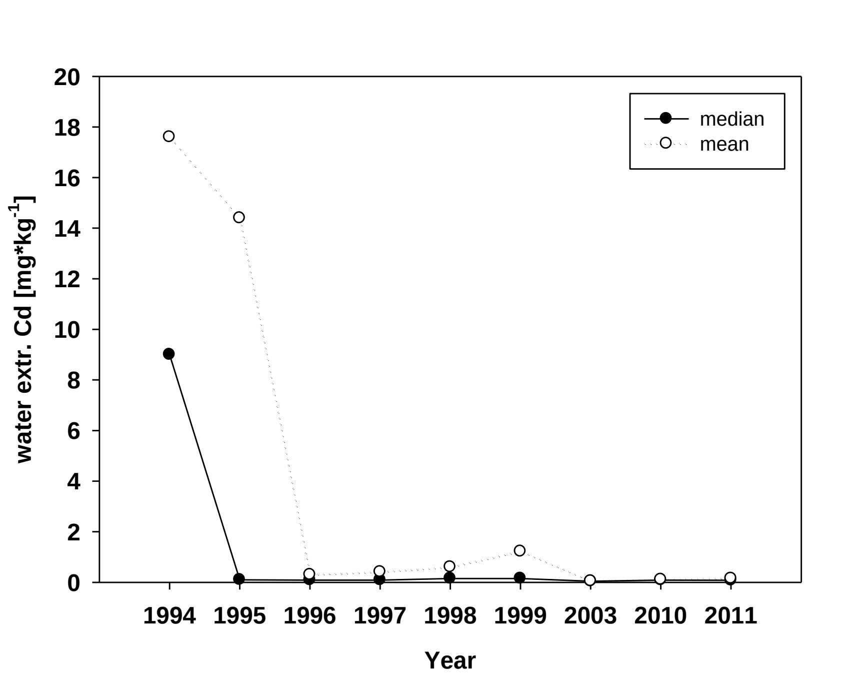
Mean yield of hay [t DM/ha] – WELZ waste



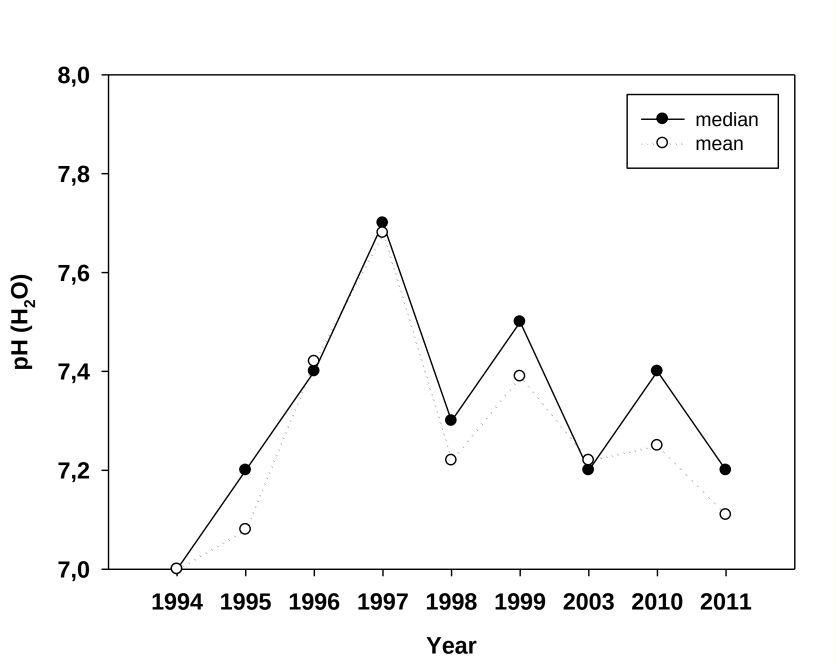
Summer 2000 – density of grass cover on Doerschel waste



water extr. Zn [mg*kg-1]
400
350
300
250
200
150
100
50
0
median
mean
1994
1995
1996
1997
1998
1999
2003
2010
2011
Year

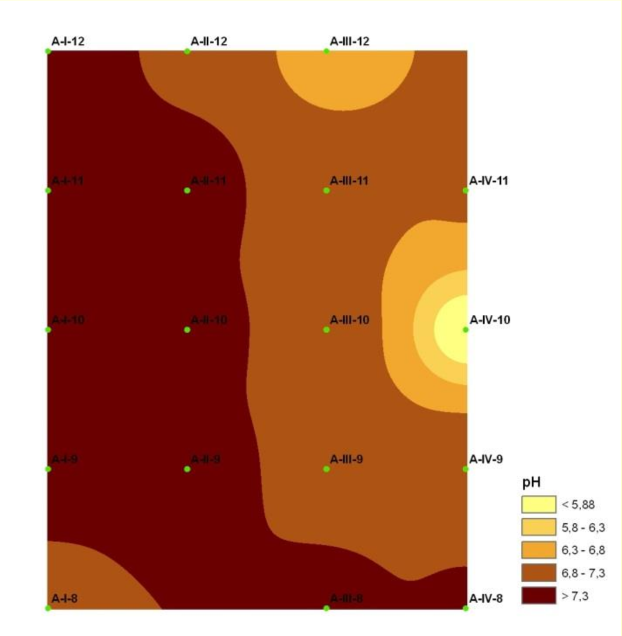


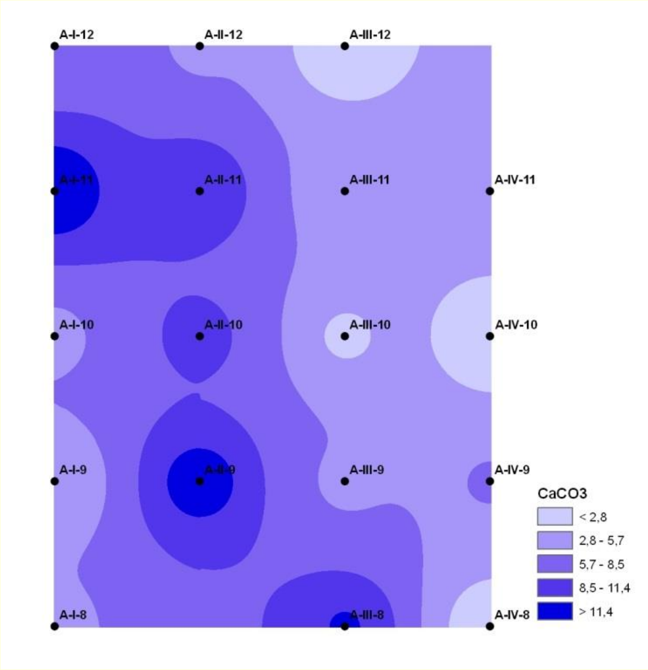
water extr. Cd [mg*kg-1]
20
18
16
14
12
10
8
6
4
2
0
median
mean
1994
1995
1996
1997
1998
1999
2003
2010
2011
Year



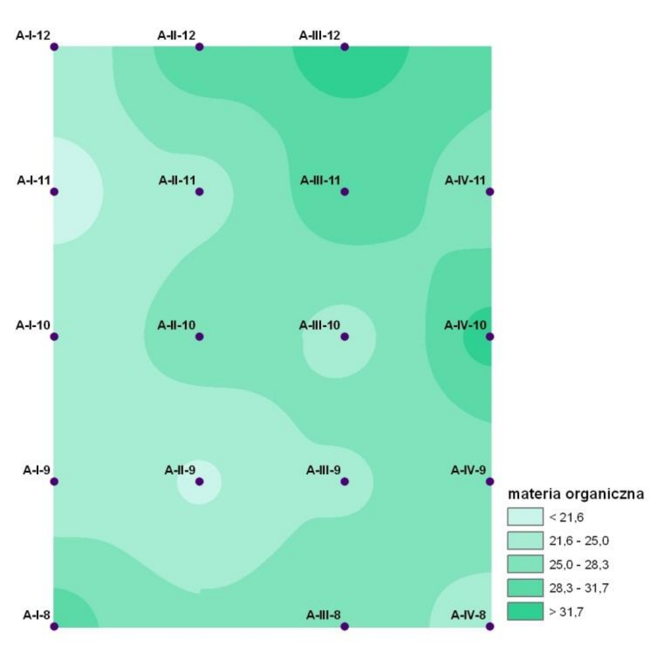
pH (H2O)
8,0
7,8
7,6
7,4
7,2
7,0
median
mean
1994
1995
1996
1997
1998
1999
2003
2010
2011
Year

pH



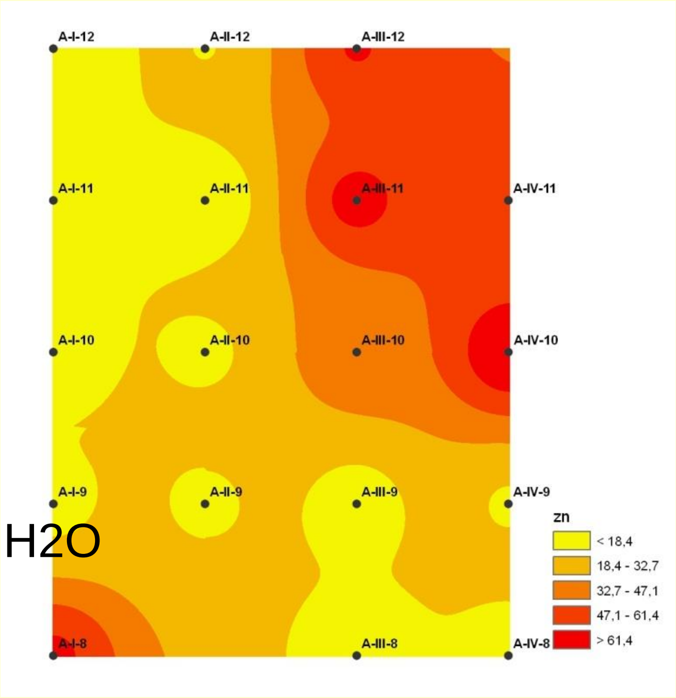


$CaCO_3$

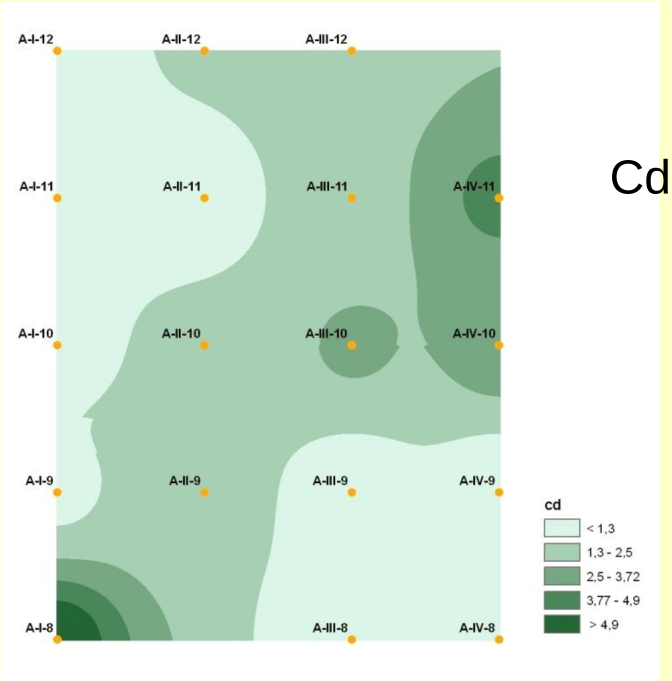


OM

Chemical properties spatially

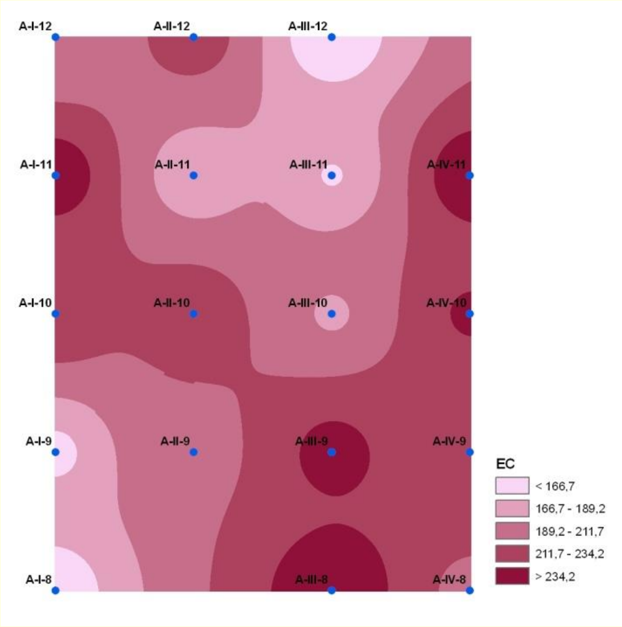


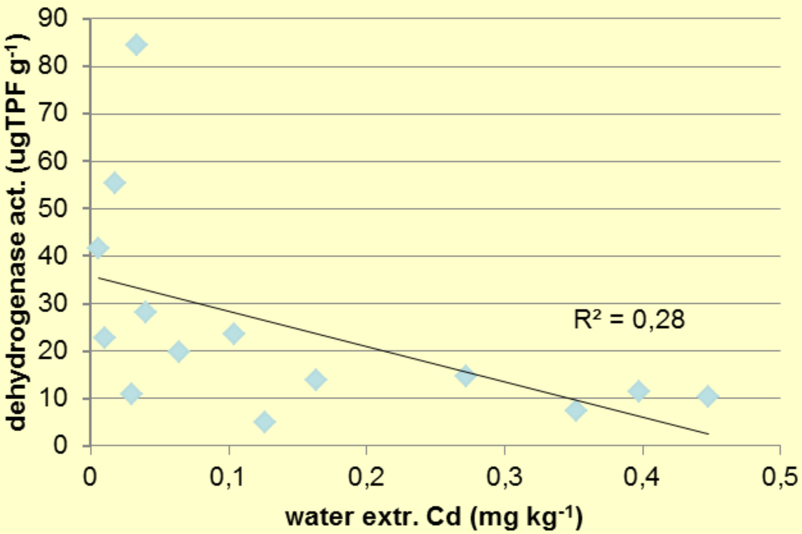
Zn in H2O



Cd in H2O

EC





Relationship between water extractable cadmium and dehydrogenases activity at Site I

Species - frequency

Artemisia absinthium		+																				
Artemisia vulgaris						+	+	+	+						+							
Betula pendula					+					+												
Calamagrostis epigejos	+	+		+	+		+	+		+				+	+	+		+	+	+		
Cardaminopsis arenosa		+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		+	+	+
Cirsium arvense							+		+													
Corylus avellana					+					+												
Daucus carota	+	+	+		+	+	+	+	+						+		+	+	+			
Deschampsia caespitosa				+																		
Echium vulgare			+	+	+						+				+							
Eupatorium cannabinum	+		+	+	+	+		+		+					+		+	+			+	
Festuca ovina	+	+	+	+	+	+	+		+	+			+		+	+	+	+	+		+	
Festuca pratensis				+	+																	
Festuca arundinacea	+	+	+						+		+						+	+		+		
Festuca rubra											+											
Galium album				+																		
Hieracium pilosella			+	+	+				+	+							+					
Hieracium piloselloides											+							+	+			
Hypochoeris glabra	+	+	+			+	+		+	+	+						+	+				
Hypochoeris radicata	+	+	+	+	+	+	+	+	+								+	+				
Oenothera biennis		+				+		+							+							
Pimpinella major						+																
Poa pratensis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+		+	+
Populus tremula										+												
Reseda lutea				+				+														+
Rumex acetosa		+	+		+	+	+			+	+	+			+	+	+		+	+	+	
Rubus caesius		+																				
Salix cinerea	+																					
Scabiosa ochroleuca															+	+	+	+				
Senecio jacobaea			+		+														+			
Senecio erucifolius						+												+	+			
Silene vulgaris					+										+							
Solidago gigantea						+									+							
Taraxacum officinale	+	+					+															
Thymus pulegioides			+	+	+				+								+	+			+	
Tussilago farfara	+																					

Dominating species

Original - Festuca ovina, Poa pratensis

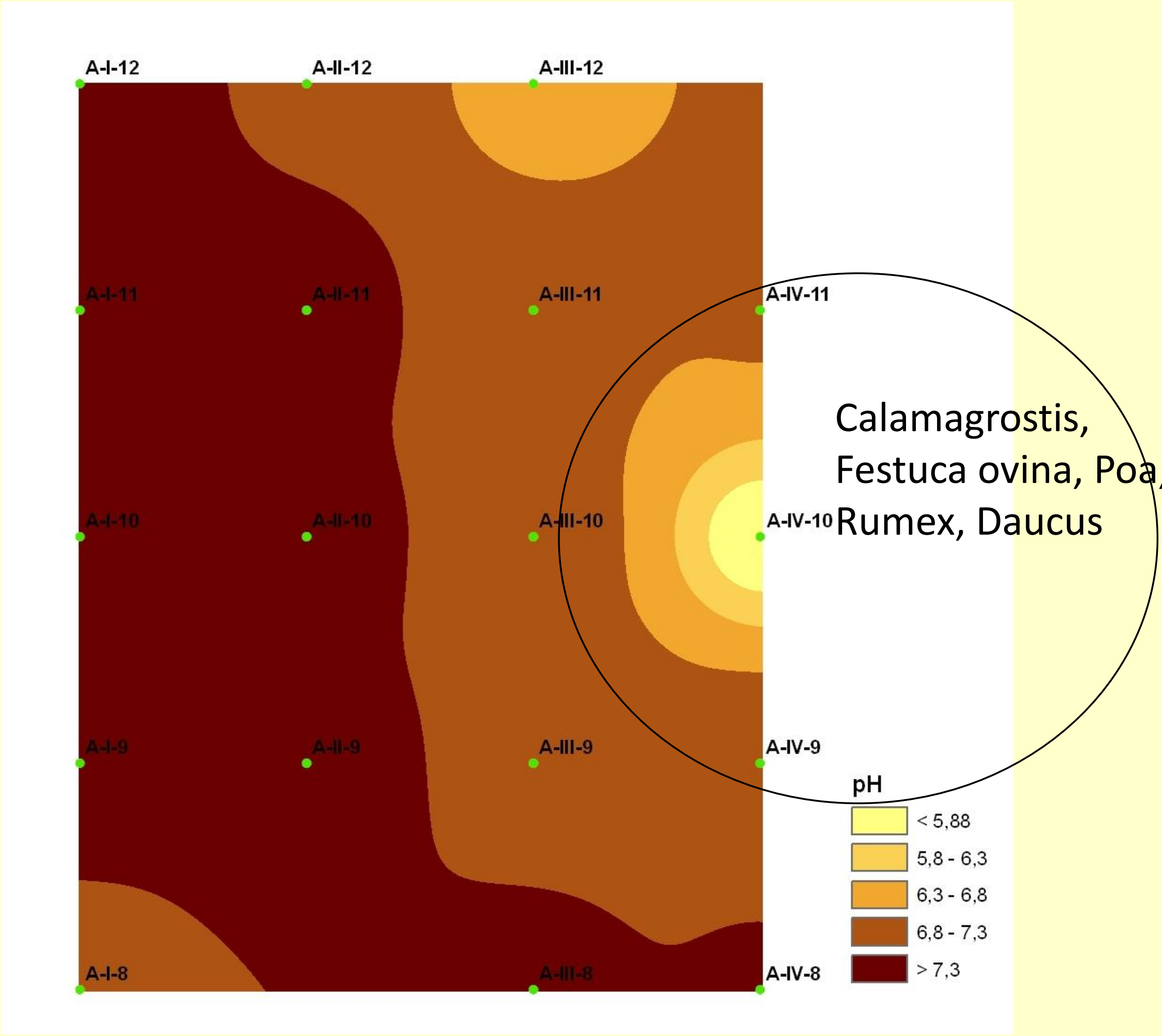
Thymus pulegioides

Eupatorium cannabinum

Hieracium piloselloides

Daucus carota

Verbascum phlomoides



Calamagrostis,
Festuca ovina, Poa,
Rumex, Daucus

Biodiversity

Snails, insects, spiders, ants, rabbits

Feeding trial

Table 11 Metal content in feedstuff used in experiment

Treatment	Pb	Cd	Zn	Fe	Cu
			mg kg $^{-1}$ dried matter		
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

* treshold value accepted in Poland

Metal contents in different tissues of experimental cattle

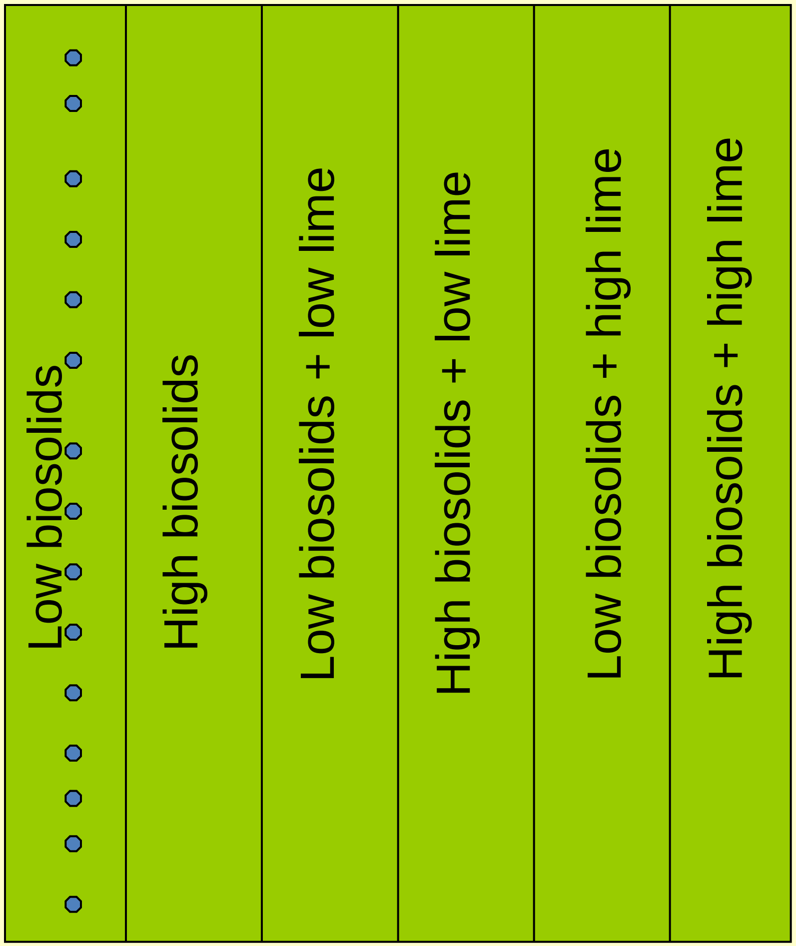
Treatment/tissue	Pb	Cd	Zn	Fe	Cu
Muscles			(mg kg^{-1} fresh matter)		
Control	0.01a	0.0010a	27.54a	7.48ab	0.29a
Contaminated hay	0.01a	0.0012a	29.05a	5.368a	0.34a
Cd amended hay	0.01a	0.0016a	25.60a	9.416b	0.48b
Cd+Zn amended hay	0.01a	0.0014a	25.25a	5.368a	0.33a
Liver					
Control	0.093a	0.034a	41.82b	44.31a	37.92
Contaminated hay	2.174b	0.134b	39.92ab	31.92a	27.17
Cd amended hay	0.071a	0.648c	36.08a	35.70a	29.67
Cd+Zn amended hay	0.039a	0.226b	38.54ab	39.27a	30.33
Kidneys					
Control	0.14a	0.17a	28.76a	36.75a	3.55b
Contaminated hay	4.06b	0.53b	29.19a	49.56c	2.89a
Cd amended hay	0.21a	2.10d	29.52a	45.57bc	3.48b
Cd+Zn amended hay	0.12a	0.776c	27.55a	40.95ab	3.23a
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

Stuczyński T., G. Siebielec, W. Daniels, G. McCarty, R. Chaney. 2007. Biological aspects of metal waste reclamation with biosolids. Journal of Environmental Quality, 36: 1154-1162

Site 2 – slag waste (Welz type)

Reclaimed 1997 with biosolids and waste lime; 23 grass cultivars of about 10 species in plot experiment

Historical data – yield, plant composition – 1997, 1998, 1999



Site II – 15th year

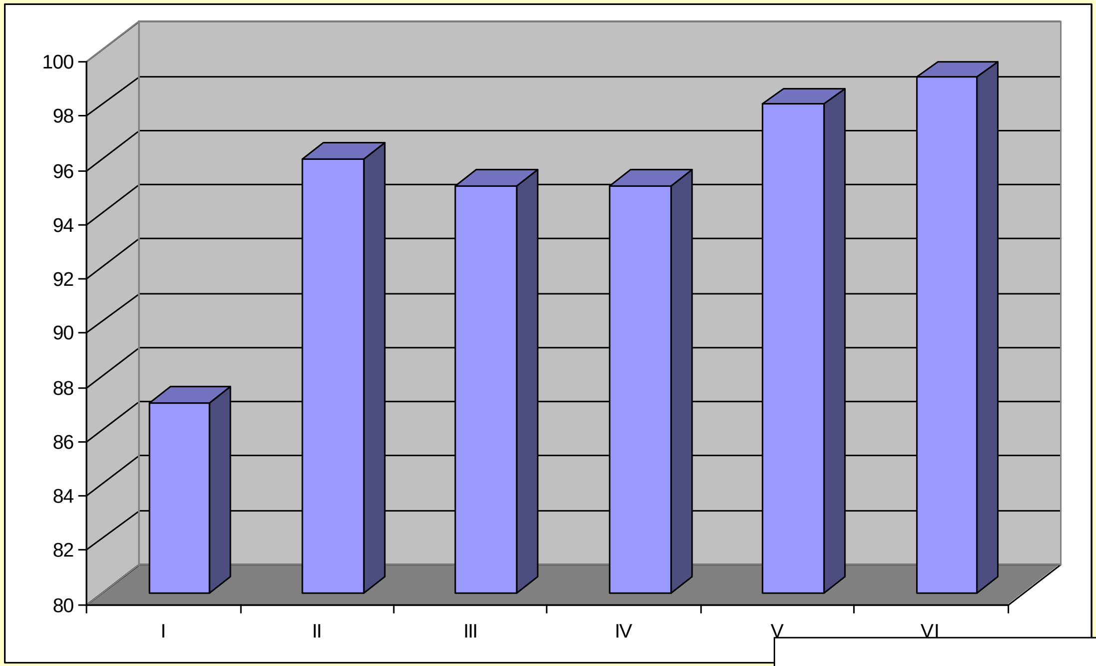
Low biosolids rate

Control

High biosolids + high lime

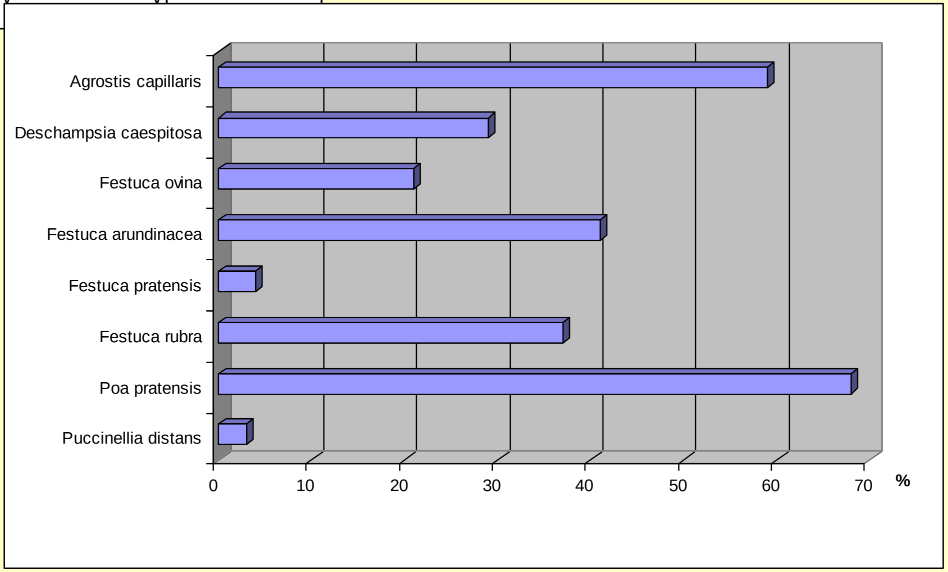
Average plant coverage within treatments

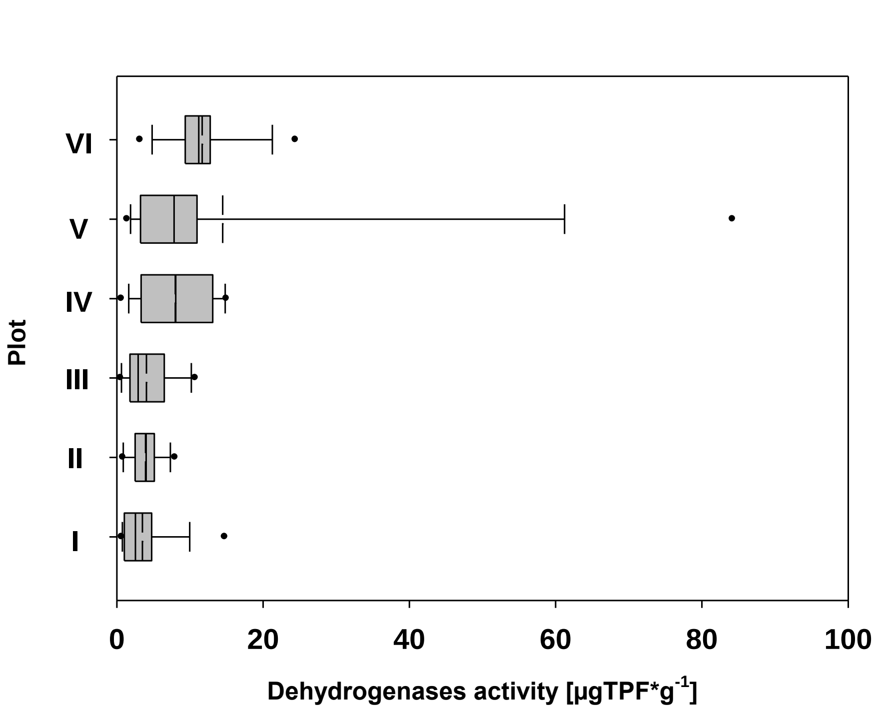
Site II – 15th year

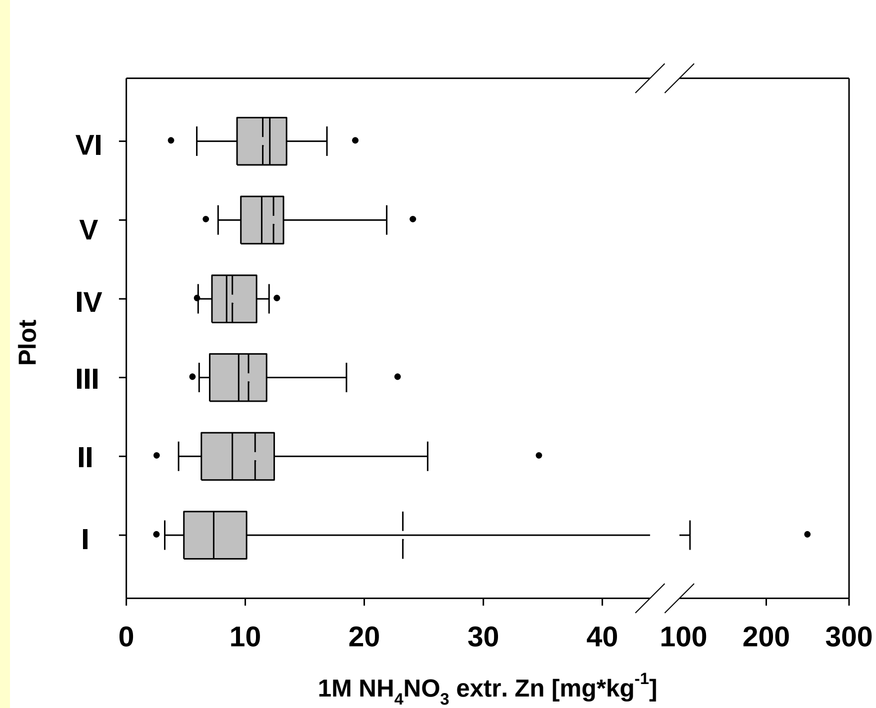


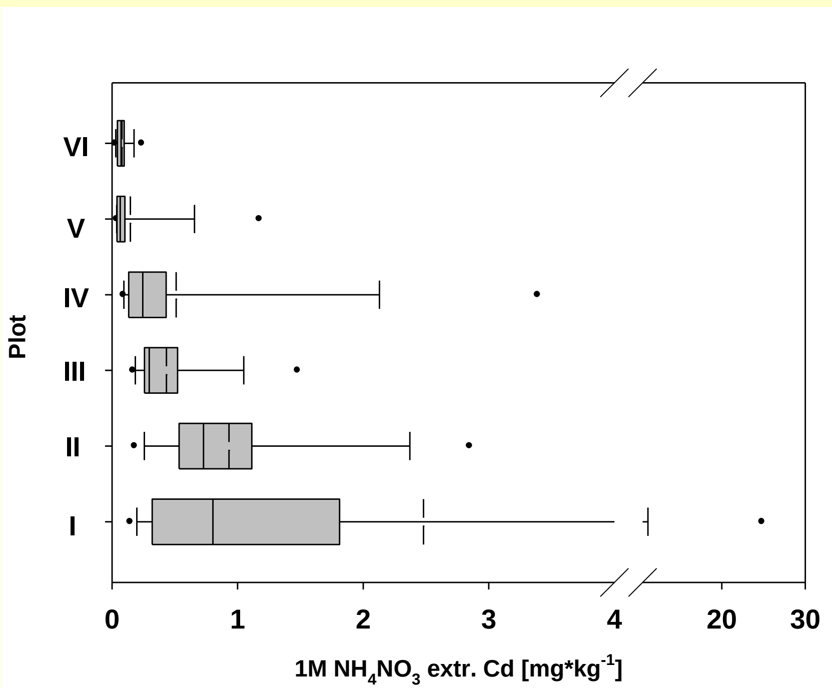
Control plot is practically barren

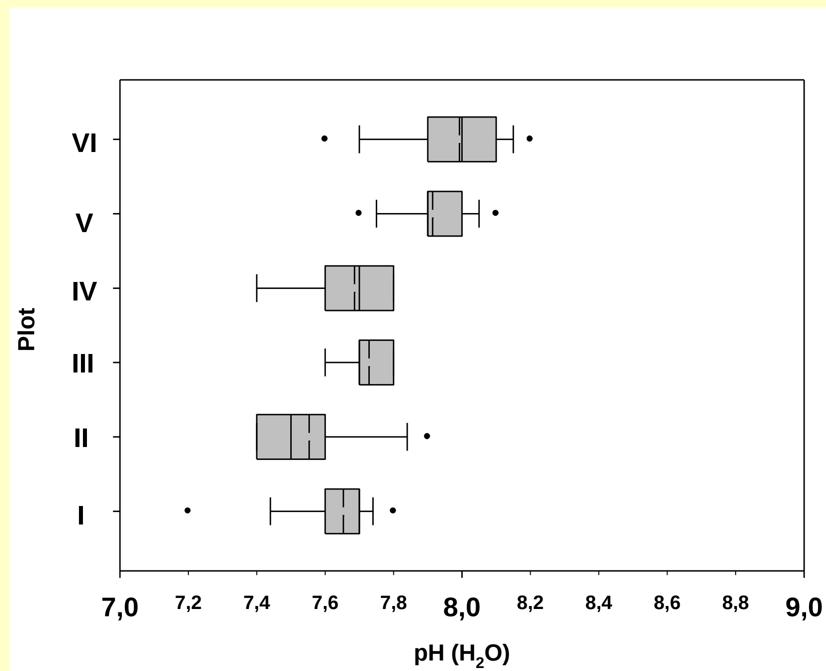
Frequency of original species(% of plots)



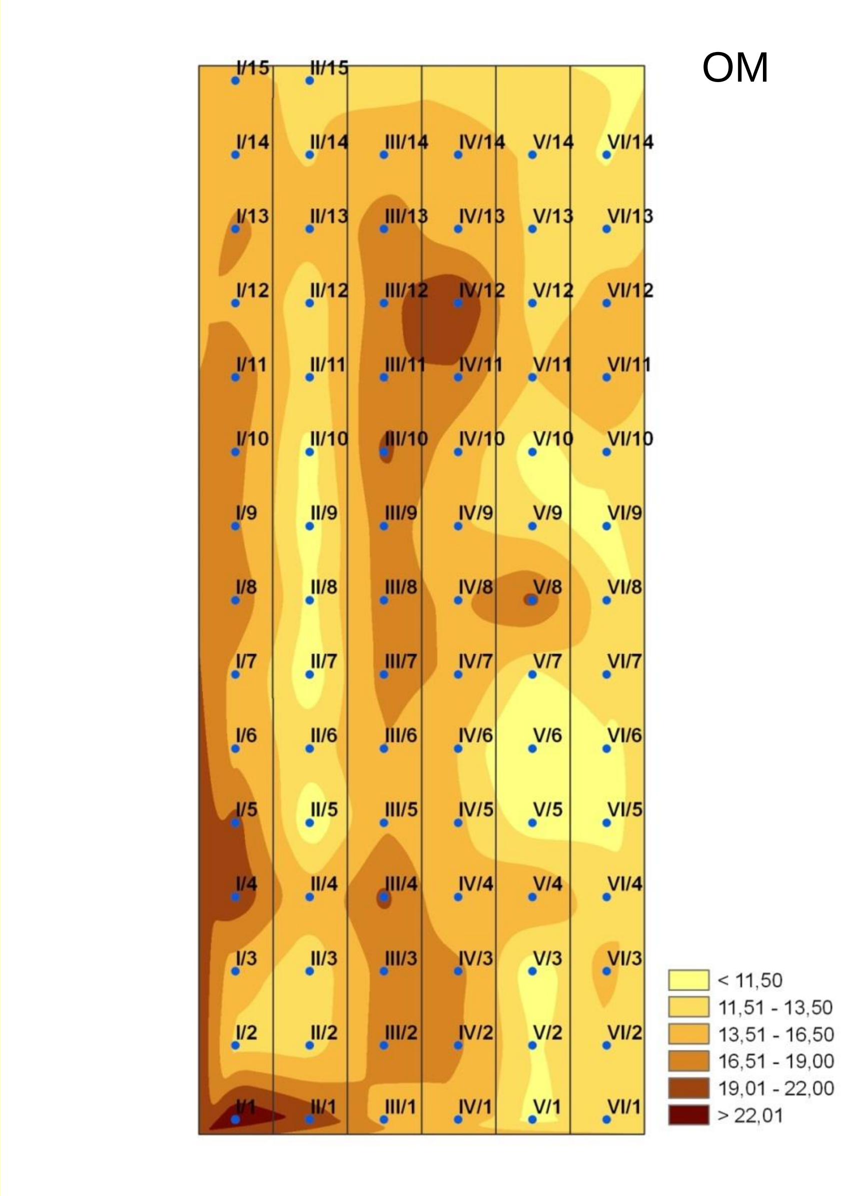

Plot
VI
V
IV
III
II
I
0
20
40
60
80
100
Dehydrogenases activity [µgTPF*g^{-1}]

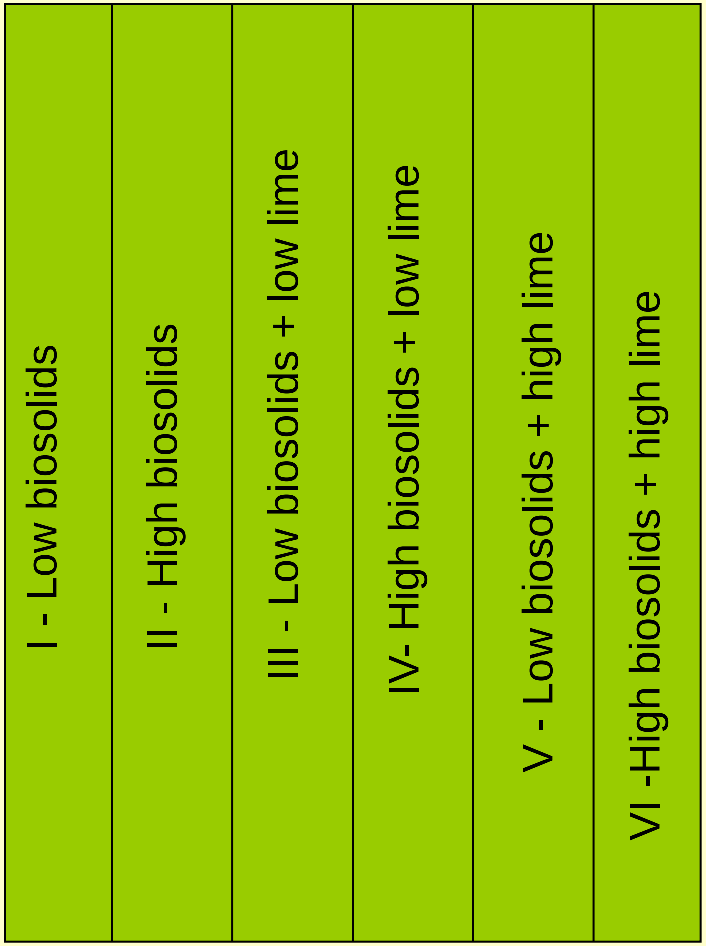

Plot
VI
V
IV
III
II
I
0
10
20
30
40
100
200
300
1M NH_4NO_3 extr. Zn [mg*kg^{-1}]


Plot
VI
V
IV
III
II
I
0
1
2
3
4
20
30
1M NH_4NO_3 extr. Cd [mg*kg^{-1}]


Plot
VI
V
IV
III
II
I
7,0
7,2
7,4
7,6
7,8
8,0
8,2
8,4
8,6
8,8
9,0
pH (H_2O)

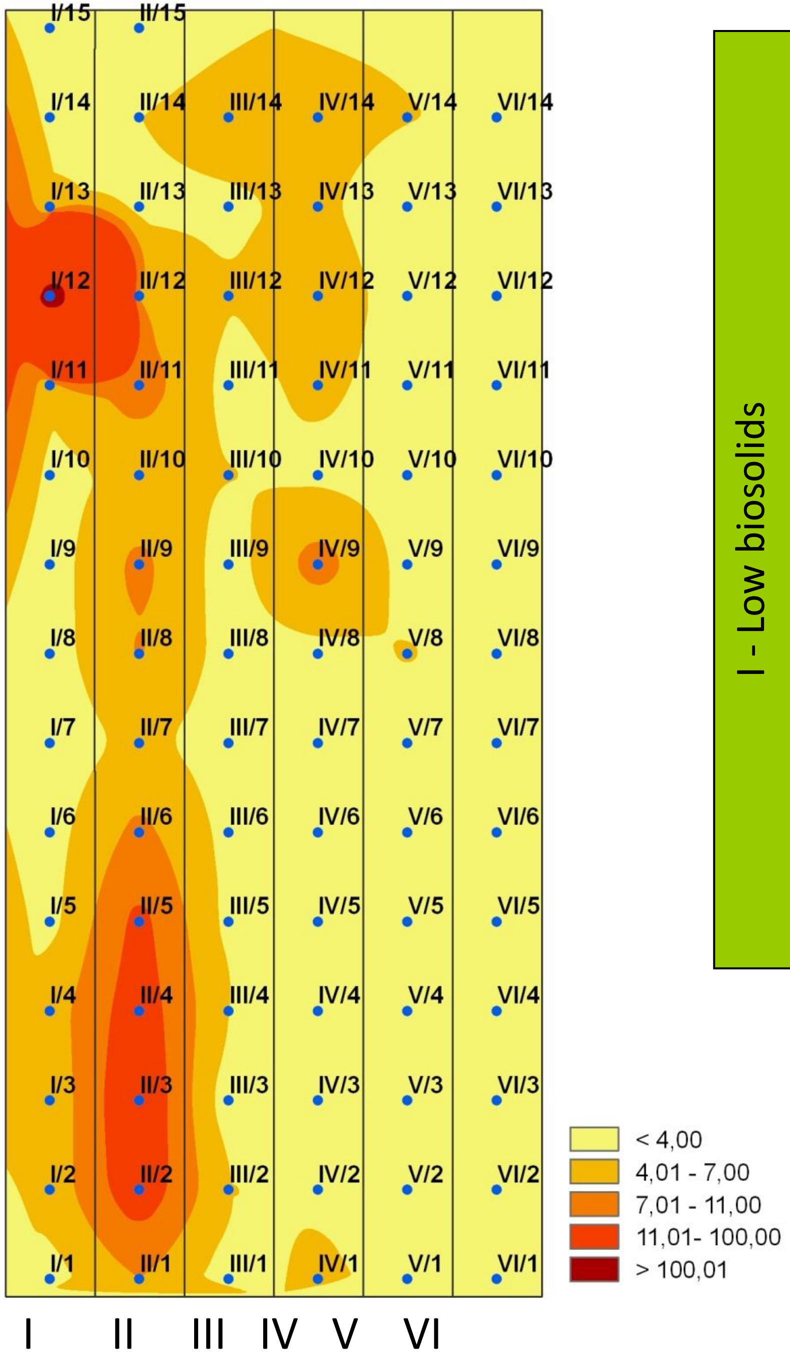
Site II –
15th year

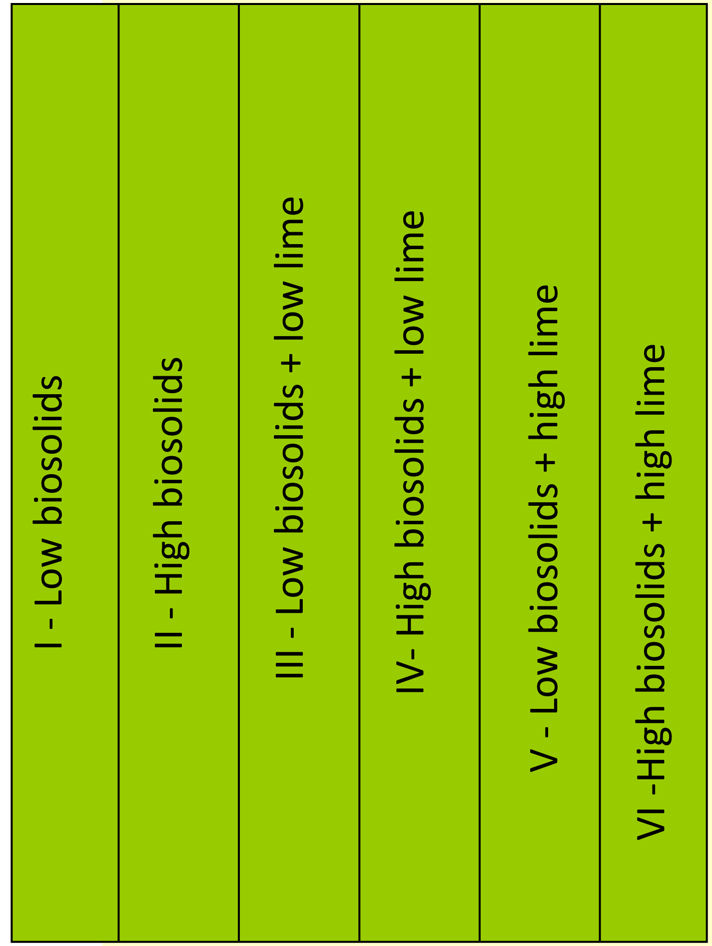




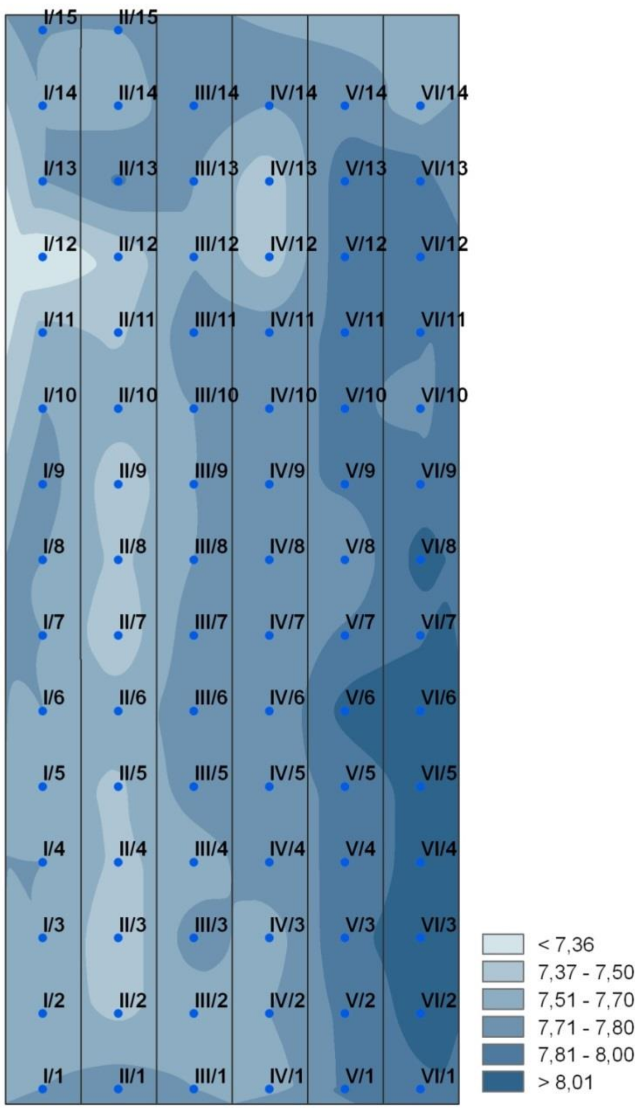
Piekary –
15th year

0.01 M CaCl2 ext Zn mg/kg

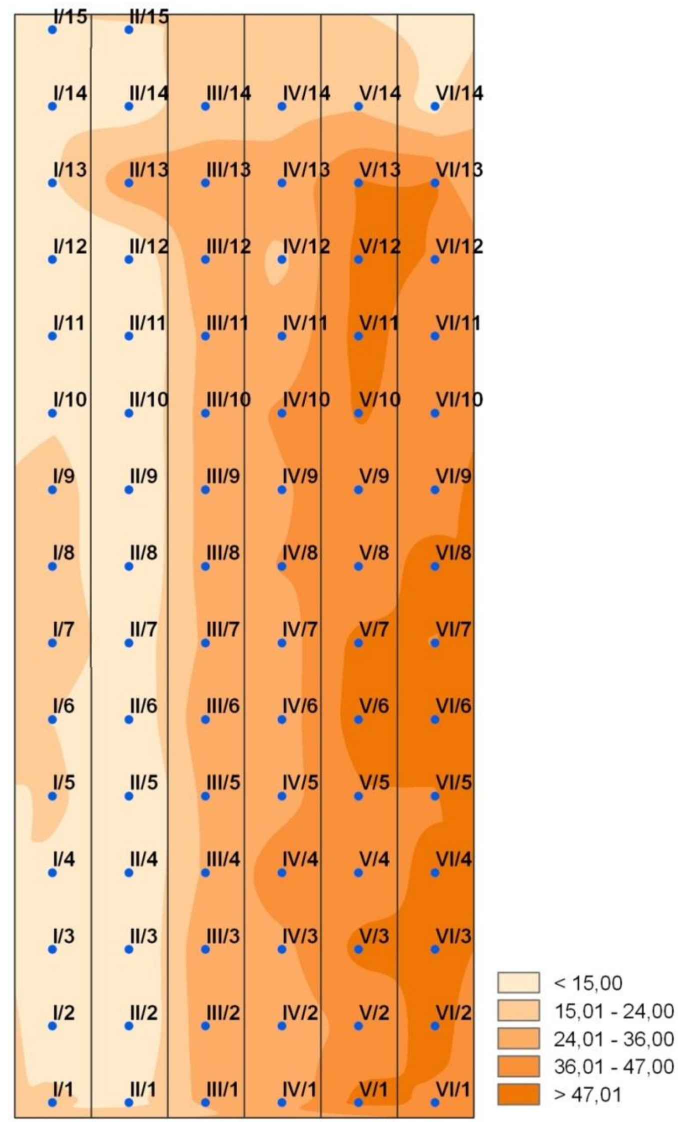




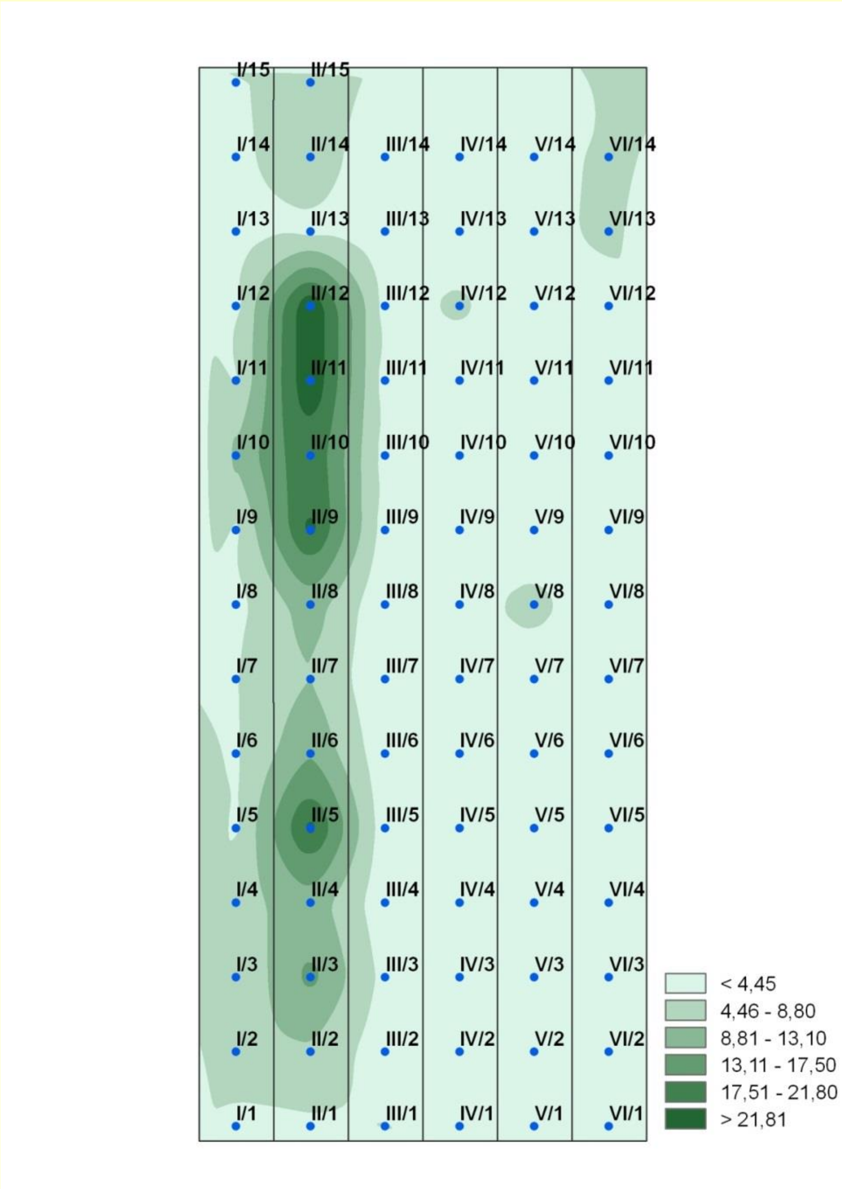
pH in H_2O



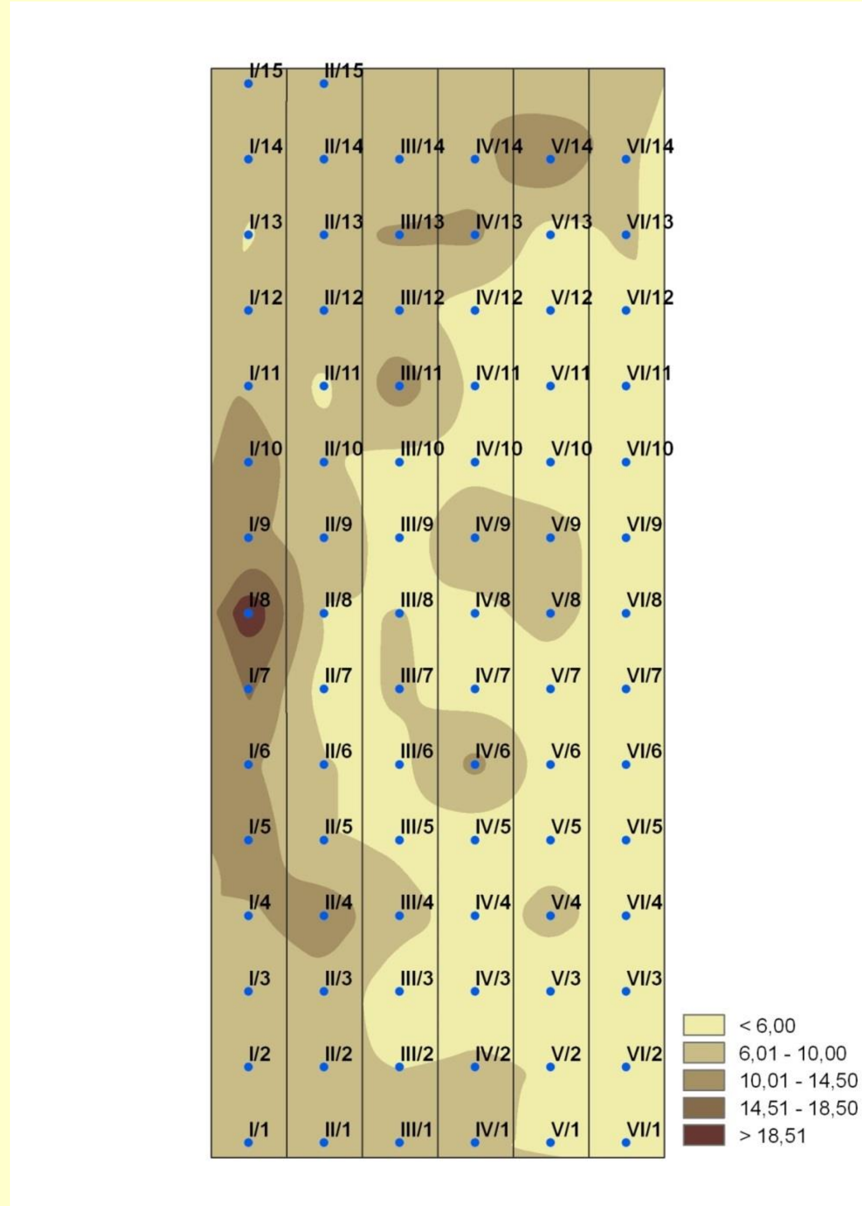
$CaCO_3$ (%)



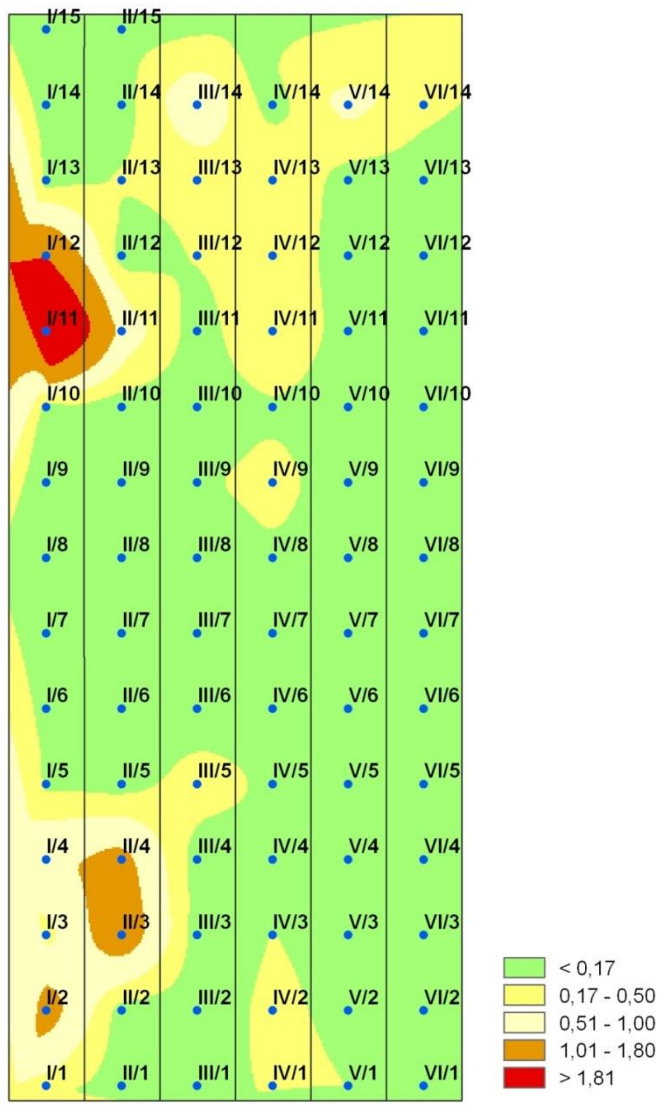
Avail P_2O_5



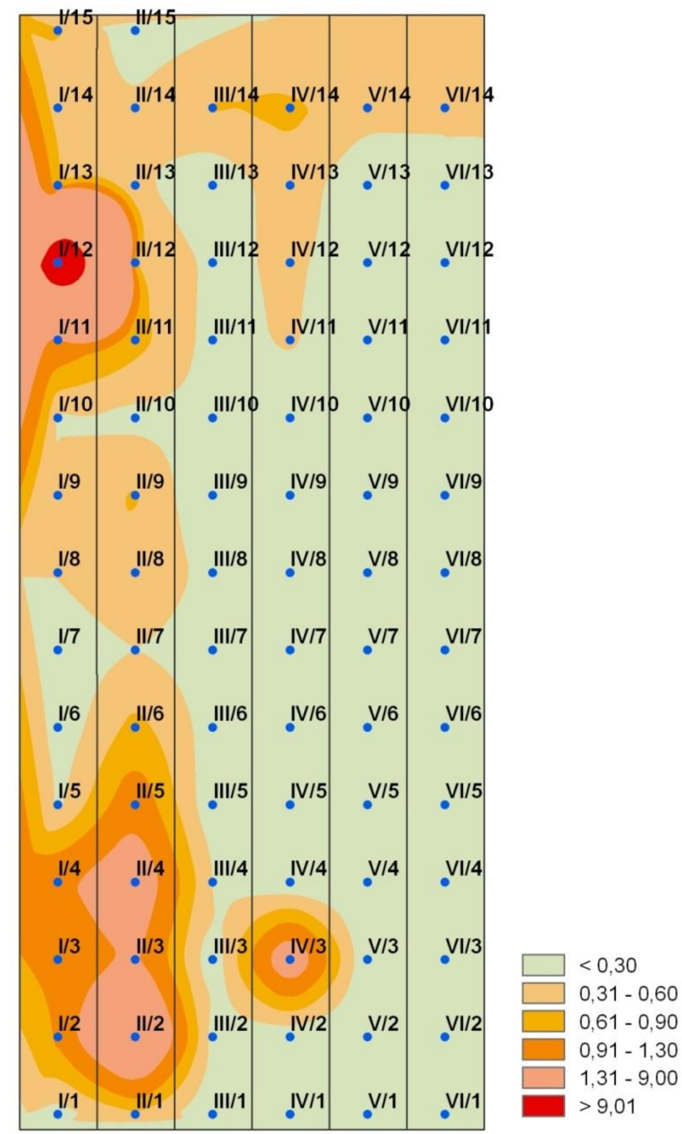
Avail K_2O



Extr Cd mg/kg



Extr Pb mg/kg



Conclusions

- The results indicate that sewage sludges ad waste lime can be successfully used for the „one-shot" reclamation of toxic smelter waste as an alternative to traditional methods.
- An integral part of each reclamation technology is the selection of grass species and cultivars that are resistant to specific type of toxicity (e.g. salinity or metals) and most effective biosolids.
- Such remediation is persistent and establishes fully functioning ecosystem, however further monitoring would be needed.
- Metal content in plants generally do not pose risk to wildlife and food chain