Phytoremediation of trace element-contaminated soils in Europe - option appraisal based on long-term field experiments

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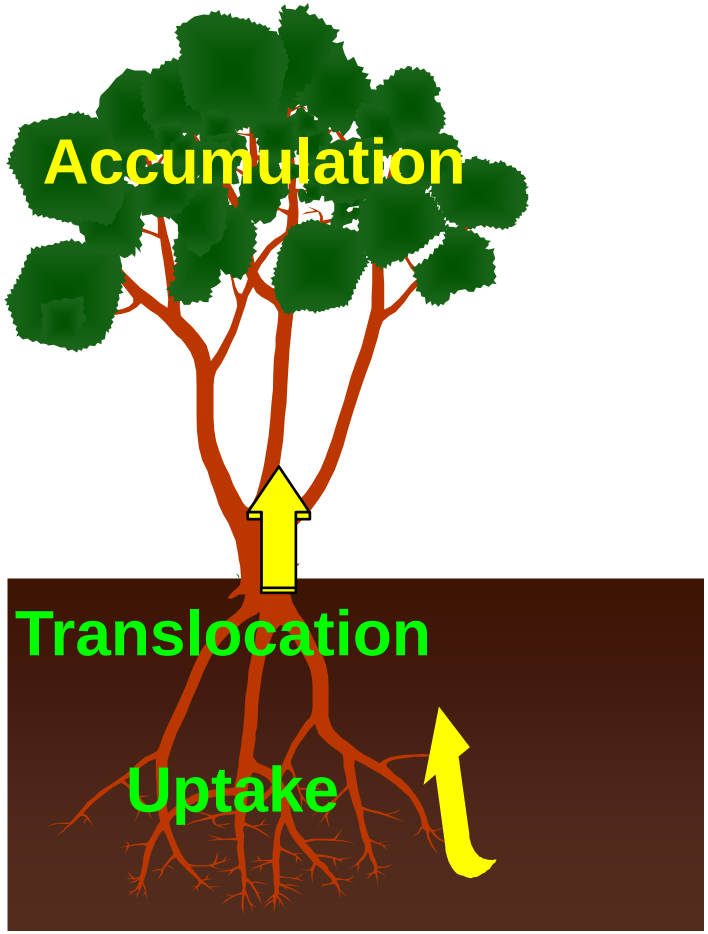
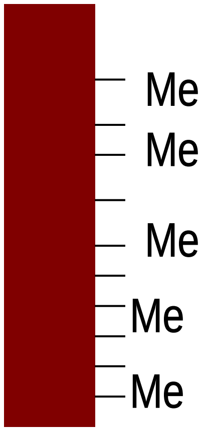
Gentle remediation options - GRO

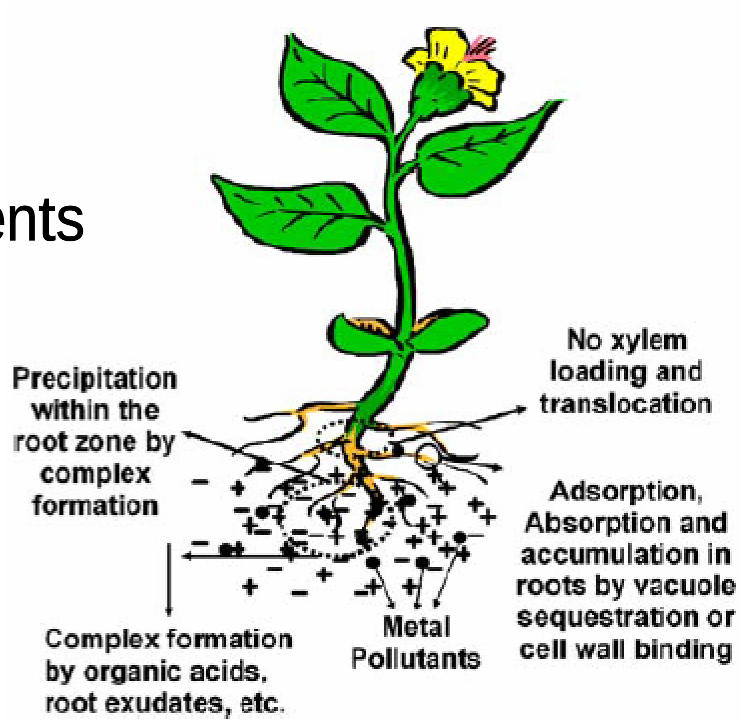
Phytoextraction



In situ immobilisation
Aided phytostabilisation
Phytoexclusion

Soil amendments





GREENLAND – Gentle remediation of trace element contaminated land* project objectives

- Assess the efficiency tested in long-term field trials
- Test the possibilities for biomass valorisation
- Evaluation of a set of soil tests to assess the pollution level, the progress and success of GRO and the monitoring of sustainability
- Enhance the efficiency of GRO (e.g. by selection of most effective plants, microbes, and soil amendments)
- Development of a decision support system and publication of a guide for practical application

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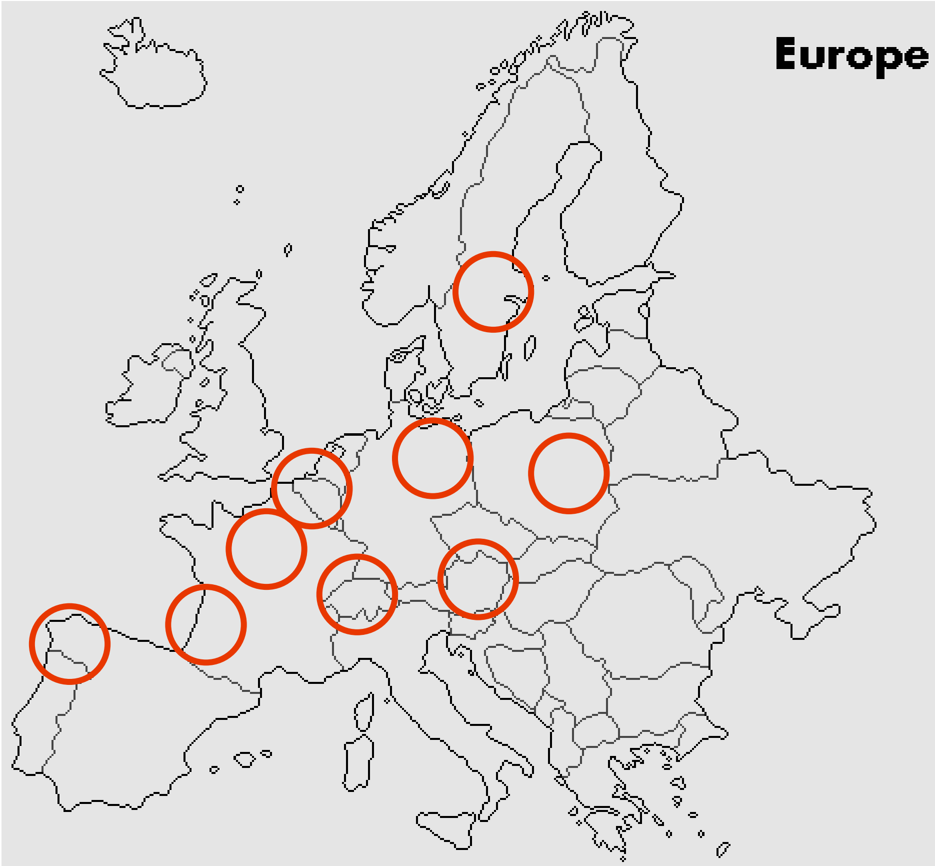
* FP7-KBBE-266124; 2011-2014

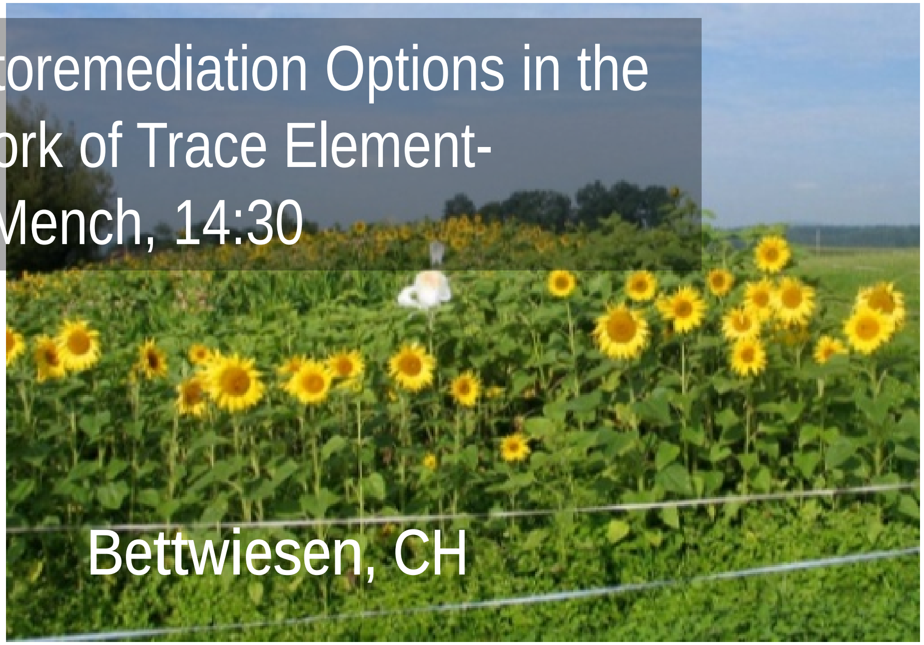
GREENLAND field trials: 17 case studies on 13 sites

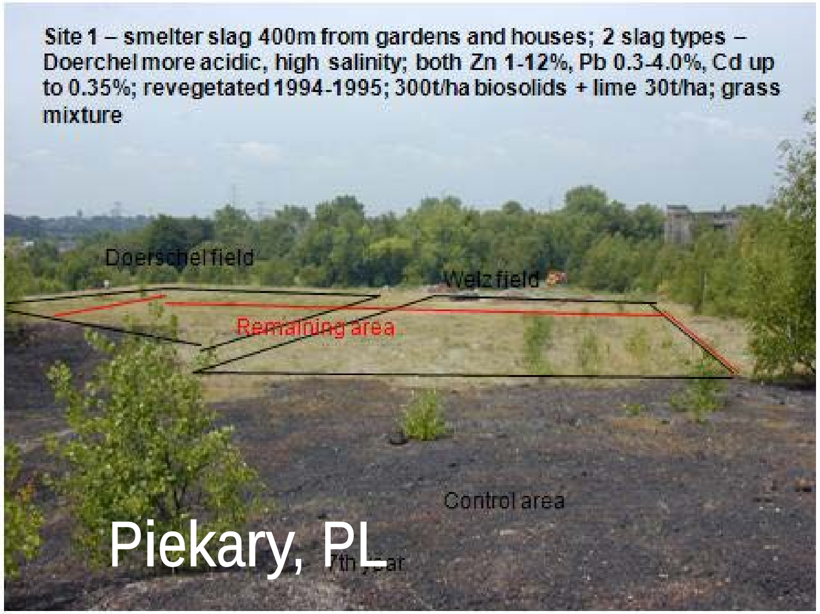


No.	Experimental coordinator	Strategy and gentle remediation technology	Plant species	Contaminants	Site type	Duration
1	UHASSELT	phytoextraction using SRC and crops	poplars, willows, maize, rapeseed	Cd, Zn	agricultural soils	8 yrs
2	SLU	phytoextraction using SRC	willows	Cd, Zn (Cu, Ni, Cr, Pb)	Commercial sludge-amended fields	19 yrs / 8 yrs
3	INERIS	phytoextraction using HA and high biomass crop	*Arabidopsis halleri* rapeseed	Cd, Zn, Pb	Marginal lands in surrounding industrial facility	6 yrs
4	CSIC	phytoextraction using HA and SRC	*Thlaspi caerulescens,* willows	Cd, Zn	tailings	3 yr
5	INRA	aided phytoextraction using high biomass crops from fast-track breeding	sunflower, tobacco sorghum	Cu and Cu/PAHs	industrial soils	6 yrs
6	LfULG	phytoextraction using SRC	poplars, willows	Cd, As, Pb	agricultural soils	8 yrs
7	PT-F	phytoextraction using high biomass crop from fast-track breeding	sunflower, tobacco	Cd, Zn (Cu, Ni, Cr, Pb)	sludged and agricultural soils on landfill	8 yrs
8	INRA	phytostabilisation and rhizodegradation (SRC and grassy cover)	Poplars, willows, grasses, vetiver	Cu and Cu/PAHs	industrial soils	8 yrs
9	CSIC	phytostabilisation	Tobacco, willows	Cu	tailings	3 yr
10	INERIS	aided phytostabilisation	Miscanthus, spontaneous grasses, shrubs, trees	Cd, Zn, Pb, As, Cu	dredged sediments	2 yr
11	AIT	in situ stabilization/phytoexclusion	barley, maize	Cd, Pb, Zn, (As, Cu)	agricultural soils	11 yrs
12	IUNG	in situ stabilization (lime, sludges)/phytoexclusion	grassland	Cd, Zn, Pb	Post-industrial soils	18 yrs
13	LfULG	in situ stabilization/phytoexclusion	crops, grassland	Cd, As, Pb	agricultural soils	8 yrs

Greenland success stories

Field Demonstrations of Phytoremediation Options in the EU FP7 GREENLAND Network of Trace Element-Contaminated Sites. Michel Mench, 14:30





In situ Immobilisation: Arnoldstein, AT

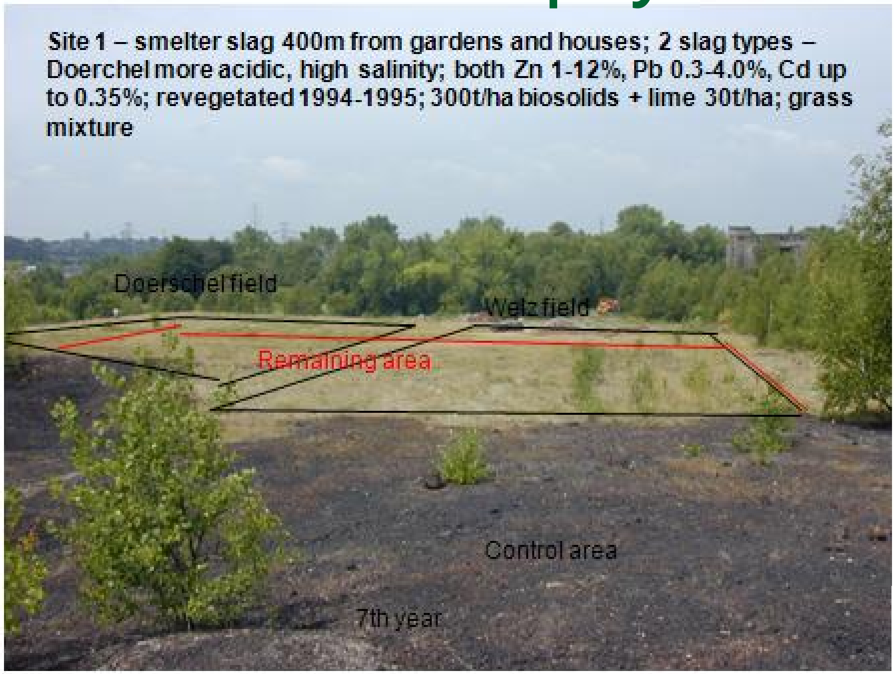
- <u>ARN-B soil</u> (moderate contamination)
- Cd (5), Pb (950), Zn (500), (As)

- <u>ARN-D soil</u> (high contamination)
  Cd (15), Pb (1600), Zn (1800), (As)



In situ remediation of Pb/Zn mining and processing impacted sites.
Wolfgang Friesl-Hanl, Wednesday, 14:50

Aided phytostabilisation: IUNG (Poland)



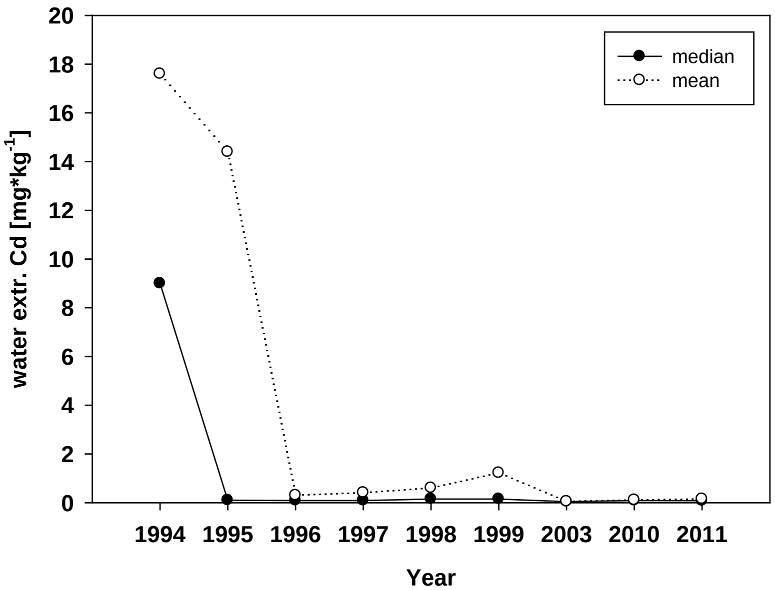


Table 3. Chemical properties of waste materials sampled before (1994) and after remediation amendment with biosolids and lime.

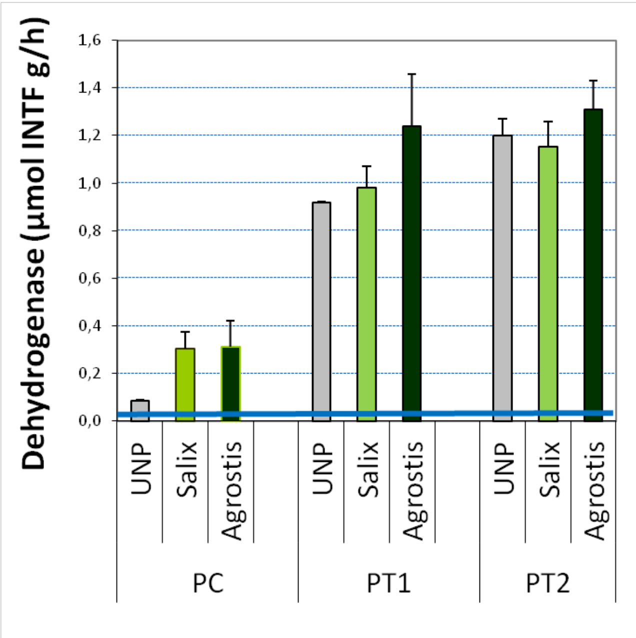
Waste material	Sampling time	Soluble Zn	Soluble Cd	Soluble Pb	pH	EC
		$mg\ kg^{-1}$				$dS\ m^{-1}$
Welz	Before	343	17.6	1.80	7.00	7.30
	1995	279	17.7	1.10	7.20	3.50
	1996	10.4	0.41	0.34	7.47	1.63
	1997	11.4	0.55	0.41	7.70	1.28
	1998	33.3	0.62	0.02	7.22	0.99
	1999	31.7	1.22	0.03	7.39	1.15
Doerschel	Before	1670	108	5.40	5.80	16.0
	1995†	983	57.4	2.90	6.00	9.00
	1996	12.4	0.66	0.42	7.44	2.98
	1997	17.9	0.80	0.40	7.74	2.06
	1998	24.1	0.48	0.01	7.28	1.53
	1999	104	0.99	0.02	7.36	2.08

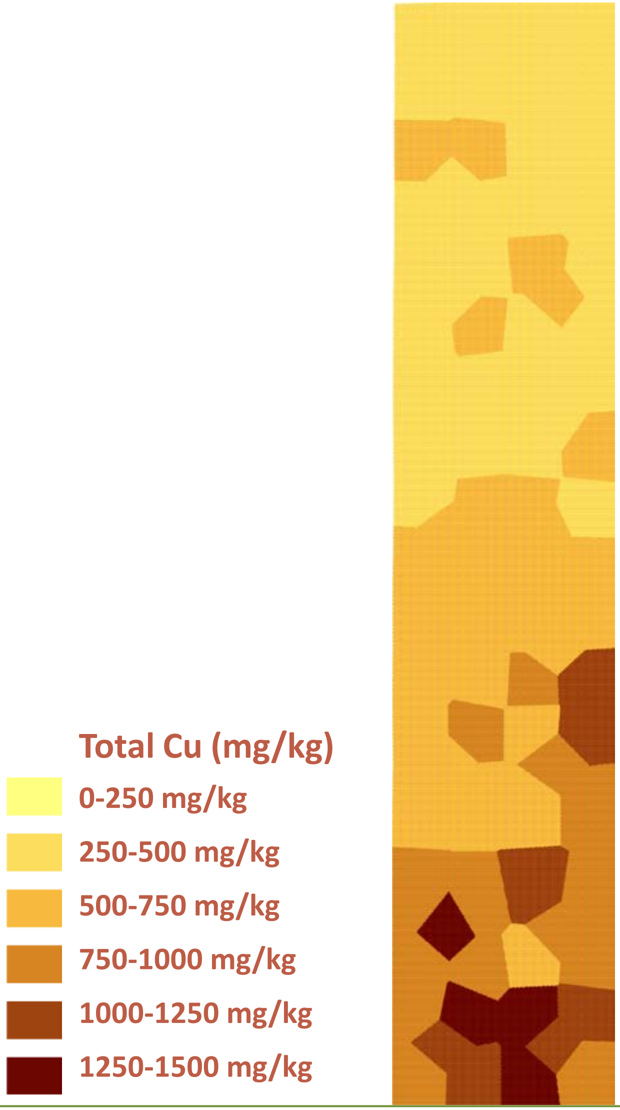
† Sampled before retreatment of Doerschel waste.

Struczynski et al. 2007

Aided phytostabilisation:

CSIC (Touro, Spain)





CSIC

Lommel (BE): Phytoextraction of Cd (removal of total pool)

based on base case values (Nele Witters, 2011) and Vangronsveld et al. (2009)

		Base case		Vangronsveld et al. (2009)	
	Biomass	Cd	Cd removal	Cd	Cd removal
	(ton dm ha^{-1})	*(mg kg^{-1} dm)*	*(kg ha^{-1} y^{-1})*	*(mg kg^{-1} dm)*	*(kg ha^{-1} y^{-1})*
EM	20 1.	8	0.022	3 (+178%)	0.06
RS	5.2	2.68	0.014	6 (+123%)	0.031
SRC-stem	4.8	25	0.120	24 (-4%)	0.12
SRC-leaves	1.2	40	0.048	60 (+50%)	0.072
Tobacco	8	24	0.19		

EM= energy maize, RS= rapeseed, SRC = SRC of willow

From 5 to 2 mg Cd/kg soil	Clean up time (yr)
SRC willow (stem+leaves, 0.34 kg/ha/yr)	17
Tobacco (0.19 kg/ha/yr)	19
Sunflower	39
Maize	62
Rapeseed	78
SRC poplar twigs	239

Phytoextraction of the labile metal pool

“Bioavailable contaminant striping”

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FEASIBILITY OF LABILE ZN PHYTOEXTRACTION USING ENHANCED TOBACCO AND SUNFLOWER: RESULTS OF FIVE- AND ONE-YEAR FIELD-SCALE EXPERIMENTS IN SWITZERLAND

Rolf Herzig,[1] Erika Nehnevajova,[1,2,3] Charlotte Pfistner,[1,2] Jean-Paul Schwitzguebel,[1,2] Arturo Ricci,[1] and Charles Keller[4]

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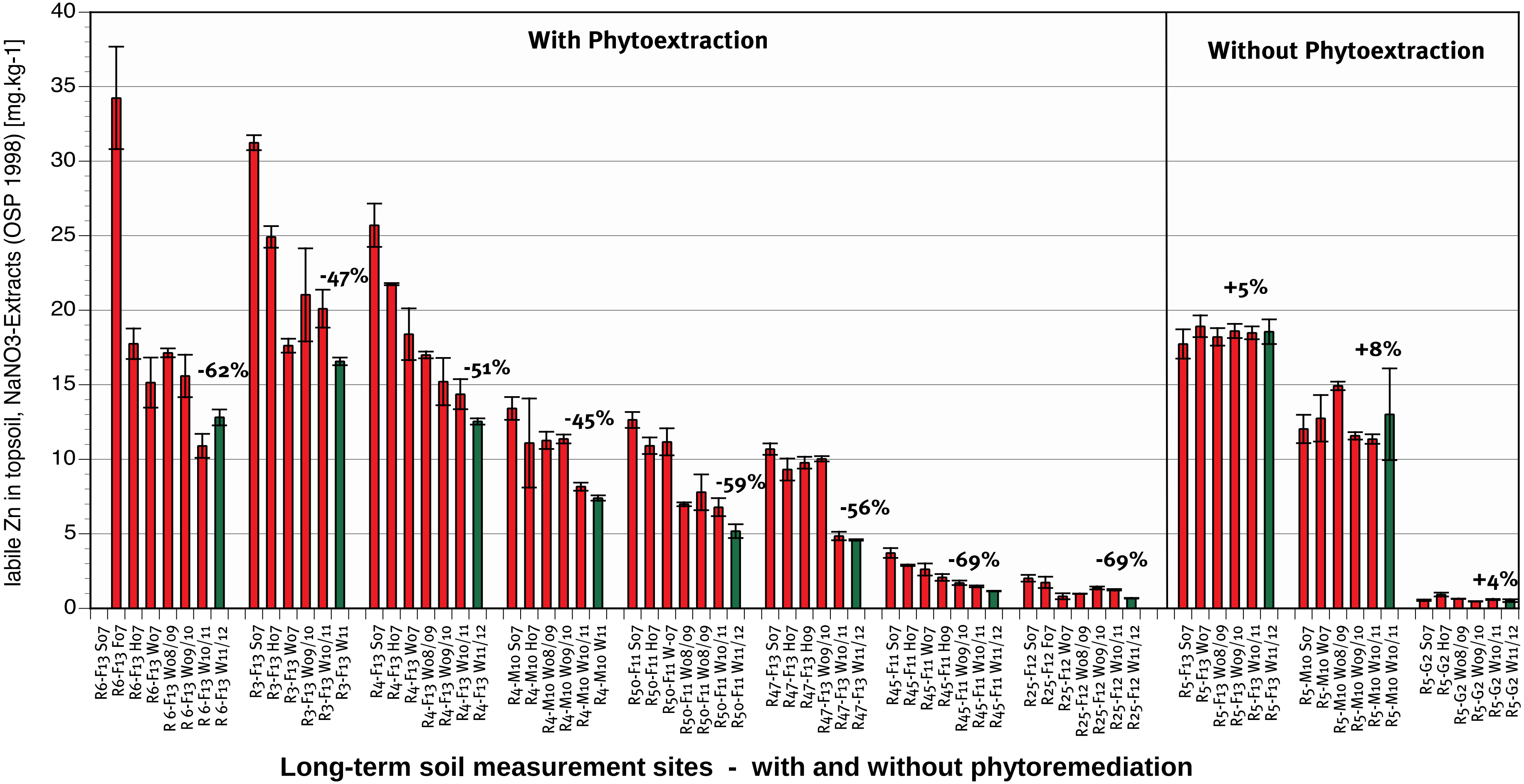
[2]*EPFL Swiss Federal Institute of Technology, (LBE), Lausanne, Switzerland*
[3]*Genetic Institute of Biology/Applied Genetics, Free University of Berlin, Berlin, Germany*
[4]*INCHEMA-Consulting AG, Zuerich, Switzerland*

Phytotech Foundation (CH): Treatment effect over 5 Years - Reduction of labile Zinc in topsoil, site Bettwiesen on landfill Grüenau-Buech-Alpenblick 2007 – 2011/12



Site Bettwiesen on Landfill Grüenau-Buech-Alpenblick after 248 Weeks of Phytoextraction with improved sunflower and tobacco in crop rotation scheme - Soil Series June 2007 – Winter 2011/12 (A07-W11/12)

Option appraisal and success stories

Best practice guidance document

Outline structure :

1. **Definitions and context – what is GRO and how does it work?**
2. **Overview of current state of development and risk management capability**
3. **Case / success stories**
4. **Potential economic, environmental and social benefits**
5. **Operating windows for GRO**
6. **Further information sources**

Appendices:

Appendix 1: Design and implementation (WP1)

Appendix 2: Cultivars and amendments (WP4)

Appendix 3: Safe biomass usage (WP2)

Appendix 4: Indicators of success and methods (WP3)

Appendix 5: DST and cost-calculator (WP5)

Appendix 6: Stakeholder engagement guidelines (WP5)

Developing a practical decision support tool (DST) for the application of phytotechnologies. Andrew Cundy, 16:30

Harmonisation of methods to assess the bioavailability of TE and development of tool set to monitor the sustainability of GRO

- To achieve a convincing argument towards the decision makers, we need a harmonisation of methods to assess the initial and residual risks and the success of GRO on a comparable (and pan-European) basis.
- To select/harmonise methods describing the bioavailable/bioaccessible TE fractions among European case studies
- To select methods which can be used as indicators for GRO success and as sustainability monitoring tools.

Plant-microbial-soil system

Time (4 years)
(bi)annual (bio)monitoring

Characterisation of soils

- **General physicochemical properties** — pH, CEC, C, N, available P (olsens), total [metal], etc.
- **Intensity of contaminant exposures** — H_2O-, $NaNO_3$-, NH_4NO_3-, EDTA-extractable [metal], soil pore water, DGT
  Ecotoxicity tests: plants, bioaccessibility (DIN 19738), earthworms, nematodes, etc.
- **Biochemical properties** — Oxidoreductase & hydrolase (C, N, P, S cycles) enzyme activities

Plant growth and establishment

- Survival, growth & coverage
- Plant ionome; contaminant accumulation

Bacterial community structure

Ecosystem services:
water filtration, C sequestration, biodiversity, etc.

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journal homepage: www.elsevier.com/locate/scitotenv

Selecting chemical and ecotoxicological test batteries for risk assessment of trace element-contaminated soils (phyto)managed by gentle remediation options (GRO)

Jurate Kumpiene [a,*], Valérie Bert [b], Ioannis Dimitriou [c], Jan Eriksson [d], Wolfgang Friesl-Hanl [e], Rafal Galazka [f], Rolf Herzig [g], Jolien Janssen [h], Petra Kidd [i], Michel Mench [j], Ingo Müller [k], Silke Neu [k], Nadège Oustriere [j], Markus Puschenreiter [l], Giancarlo Renella [m], Pierre-Hervé Roumier [j], Grzegorz Siebielec [f], Jaco Vangronsveld [h], Nicolas Manier [n]

Significant correlations between extractable Cd and biological responses for treated and untreated sites

	Cd Extractions									
	AqReg	EDTA	NH_4NO_3	$NaNO_3$	H_2O	C_{DGT}	C_{sln}	R_{DGT}	+*	-*
Plantox										
Lettuce										
shoot DW mass							-X			-2
shoot FW mass		x							+1	
Turnip										
seed germination		x							+1	
shoot DW mass		-X	**-X**	**-X**	**-X**	x	-x		+1	-12
Dwarf beans										
shoot mass DW		-x	-X-x	-X	-X					-8
primary leaf FW mass		**X**	-X	-X	-X				+3	-6
root FW mass		-X	**-X-X**	**-X-X**	-X-X	**-X**	-X	X	+2	-23
shoot length	x	-x	**-X**-x-x	**-X**	-X	-x			+1	-12
Soil invertebrates										
Earthworm avoidance	**-X**	-X	x	x		-x		-X	+2	-8
Nematode growth		X				x		**-X**	+3	-3
Nematode reproduction			-X							-2
Dwarf bean stress enzymes										
Leaves										
ME		X	**XX**x	**XX**-X	**X**x	X	X	**-X**	+21	-5
ICDH		X**X**	X**X**	**XX**x-x	**XX**	Xx	X	**-X**	+26	-4
GPOD		x	**XXX**	**XX**-x	**X**x	X	X	-x	+22	-2
Roots										
ME	X	-x	X**X**	X**X**	x**X**	**X**	**X**	-X	+22	-3
GlDH	X		X**X**	X**X**	X**X**	x	**X**		+21	
GPOD	**X**		X**X**	X**X**	X**X**	**X**	X	-x	+23	-1
Sum of positive and	**+8**	**+15**	**+35**	**+32**	**+27**	**+16**	**+14**	**+2**	**+149**	
negative correlations*	**-3**	**-9**	**-21**	**-20**	**-13**	**-5**	**-5**	**-15**		**-91**

Significance level: x- 90%; X- 95%, **X**- 99%; "-" indicates negative correlation.

* The correlations were weighted by allocating 1 point for those having 90% significance level, 2 points for correlations with 95% significance level, and 3 points for correlations with 99% significance level separately for positive (+) and negative (-) correlations.

Plantox responses: site Arnoldstein

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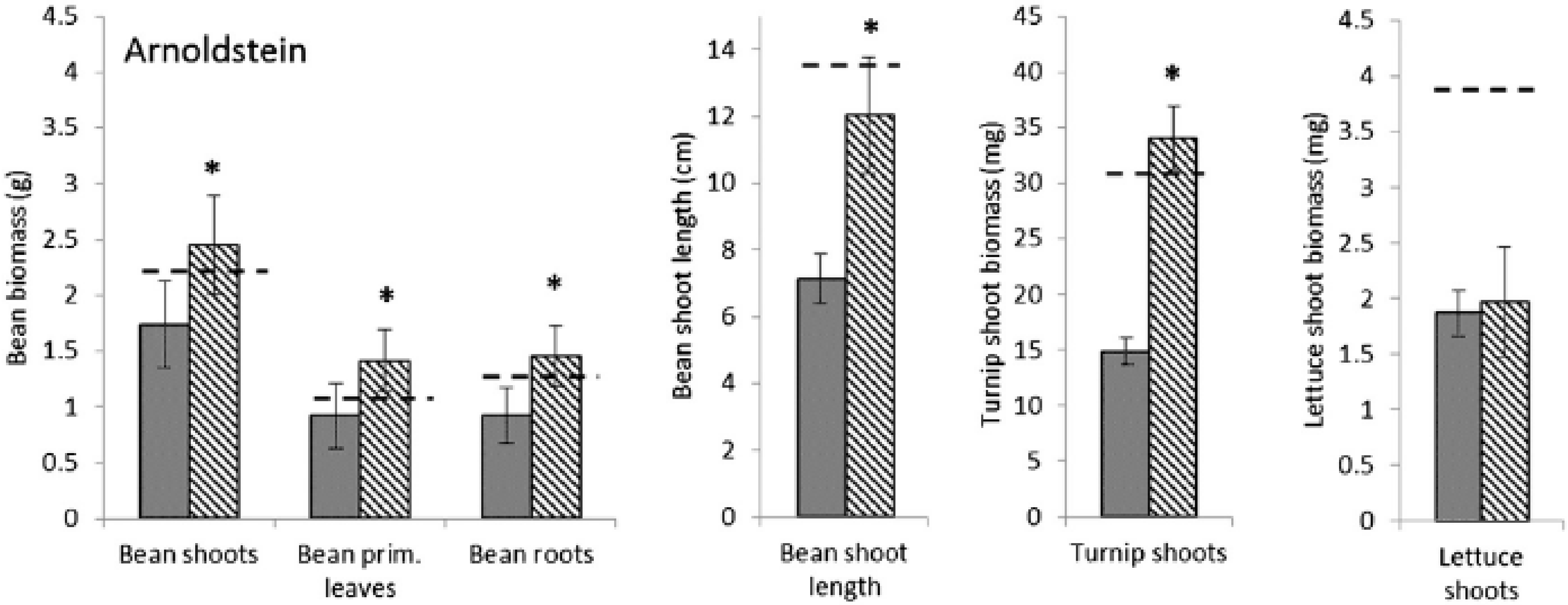


Fig. 2. Plantox responses. The biomass of above ground plant parts expressed in dry weight and per pot and root biomass in fresh weight. The dashed line represents the mean value obtained in uncontaminated control soil. Gray bar = untreated soils; hatched or dotted bar = treated soils. For Biogeco and Piekary II, hatched bar = OMDL and LB-L treatments, respectively; dotted bar = OMZ and LB-H treatments, respectively. The stars represent statistical differences at 95% confidence level between untreated and treated soils.

Earthworm behaviour

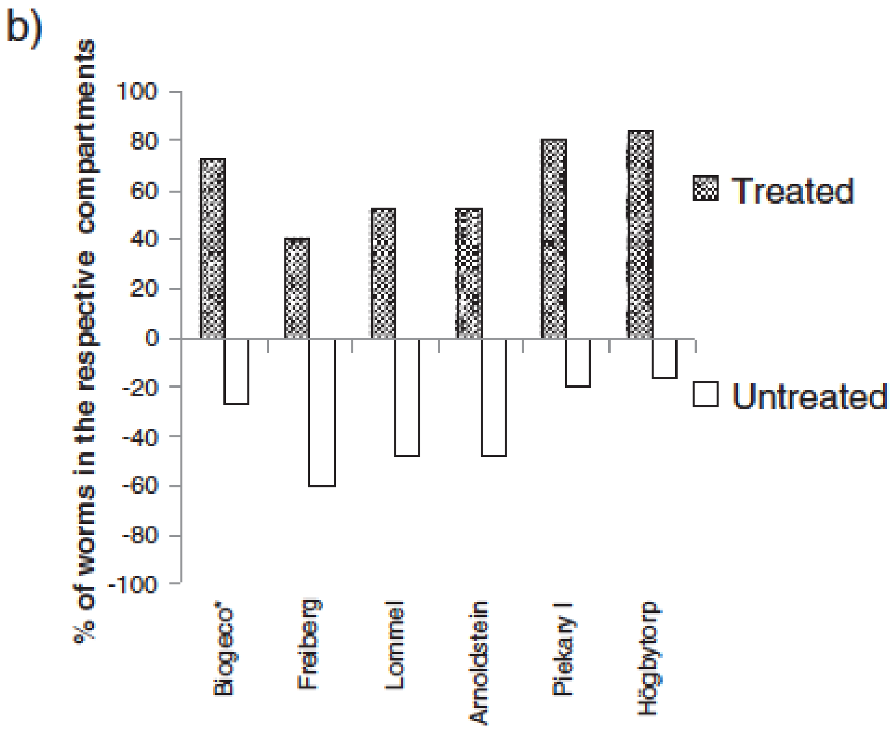


Fig. 4. Behavior of worms *Eisenia andrei* in tested soils. (a) Behavior of worms in studied soils and the ISO control soil. The dashed lines represent the threshold for significance (±60%); (b) behavior of worms in the treated soils as compared with the untreated ones. *OMDL treated Biogeco soil.

Assessment of biomass valorisation options

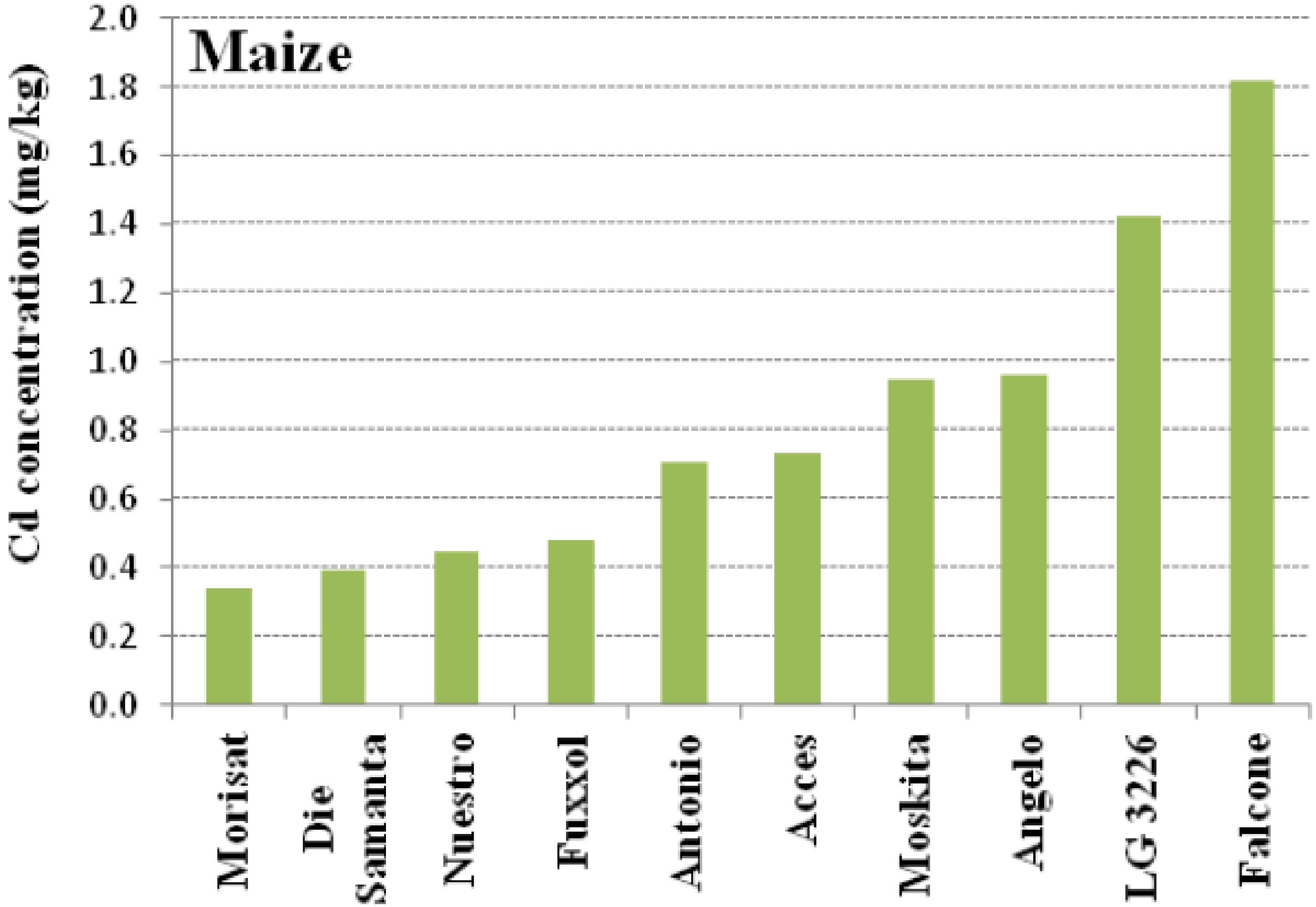
- to review existing processes and types of biomass; to compile information on current and under development processes
- to test various types of plant biomass collected on case study sites
- to assess advantages and limitations regarding technical aspects, regulations, acceptance and costs
- Treatment options:
  - Incineration
  - Gasification
  - Anaerobic digestion
  - Solvolysis
  - Pyrolysis

Processing of Plant Biomass Harvested at Trace Element-Contaminated Sites Managed by Gentle (Phyto) Remediation Options. Valerie Bert, 15:30

Improvement of GRO efficiency

- Selection and testing of more efficient plant species, varieties, clones
- Selection and testing of more efficient soil amendments
- Selection and testing of more efficient microbial strains (rhizobacteria, endophytes)
- Application of agronomic practices for improving GRO efficiency

Selecting TE-excluding crops for phytoexclusion



Testing novel combinations of amendments for stabilization of metals in heavily contaminated soils. Grzegorz Siebielec, 17:00

Development of a decision support tool and a best-practice guidance document

- Draw together data from other WPs, and develop and test best-practice guidance documentation and tools to allow stakeholders, problem-holders and end-users to appraise the various options available, examine the potential for use of the biomass produced, and refer to a harmonised methods protocol.
  - → best-practice guidance document for the application of GRO at field-scale
  - → Guidelines for stakeholder participation, engagement and empowerment when implementing GRO
- To develop and trial / evaluate a **decision support tool** (based on Greenland and other case studies), focused on GRO, which can be integrated into existing, well-established and utilised (national) DSTs / decision-frameworks.

Developing a practical decision support tool (DST) for the application of phytotechnologies. Andrew Cundy, 16:30

GREENLAND: consortium

- 1 Markus Puschenreiter, University of Natural Resources and Life Sciences, Vienna (Coordinator)
- 2 Jaco Vangronsveld, Universiteit Hasselt
- 3 Jurate Kumpiene, Luleå tekniska universitet
- 4 Michel Mench, Institut National de la Recherche Agronomique
- 5 Valerie Bert, Institut National de l'Environnement industriel et des Risques
- 6 Andrew Cundy, University of Brighton
- 7 Petra Kidd, Consejo Superior de Investigaciones Científicas
- 8 Giancarlo Renella, University of Florence
- 9 Wolfgang Friesl-Hanl, Austrian Institute of Technology
- **10 Grzegorz Siebielec, Instytut Uprawy Nawożenia I Gleboznawstwa - Państwowy**
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- 12 Ingo Müller, Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie
- 13 Jannis Dimitriou, Sveriges lantbruksuniversitet
- 14 Xose Quiroga Troncoso, Tratamientos Ecológicos del Noroeste SL
- 15 Ryszard Bajorek, ATON
- 16 Patrick Lemaitre, Innoveox
- 17 Cyril Aymonier, CNRS-ICMCB

Thanks for your attention!

Stakeholder engagement/empowerment in all steps of GRO implementation

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Developing principles of sustainability and stakeholder engagement for "gentle" remediation approaches: The European context

CrossMark

A.B. Cundy[a,*], R.P. Bardos[a,b], A. Church[a], M. Puschenreiter[c], W. Friesl-Hanl[d], I. Müller[e], S. Neu[e], M. Mench[f], N. Witters[g], J. Vangronsveld[g]

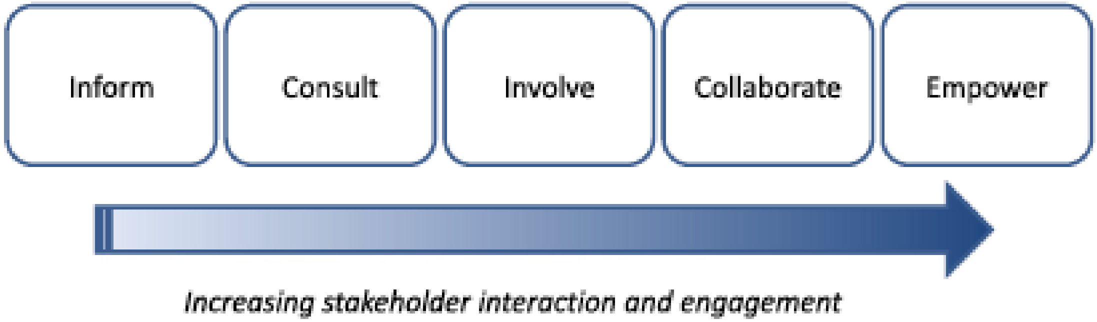

Fig. 3. Spectrum of stakeholder engagement and empowerment activities (after REVIT Project, 2007). Note that the lower arrow shows direction of increasing depth of stakeholder interaction and engagement and is not intended to show a "flow" of activities, as stakeholder engagement activities are frequently iterative and non-linear in nature and may involve the full range of these involvement measures (see text for discussion).

Development of a decision support tool