Experience with Phytoremediation of Heavy Metal Contaminated Land by Energy Crops: Phyto2Energy and MISCOMAR Projects

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PHYTO2ENERGY

Phytoremediation driven energy crops production on heavy metal degraded areas as local energy carrier

The research leading to these results has received funding from European Community´s Seventh Framework Programme (FP7/2007-2013) under Grant agreement 610797.

Some facts about the Phyto2Energy project

- Acronym: **Phyto2Energy**
- Funding scheme:

  Industry Academia Partnerships and Pathways under Maria Skłodowska Curie Actions of the 7FP

- Start up date: **1 Feb 2014**
- Duration : **48 months**

Consortium of 6 partners

R&D

IETU

Politechnika Śląska

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

Industry

ISPE

VITA34 BioPlanta

ProBiotics Polska

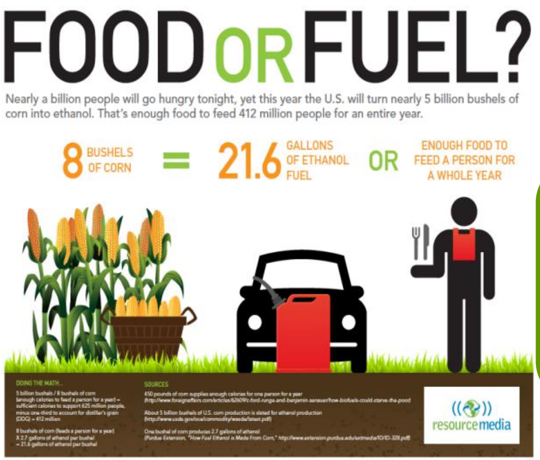
Why PHYTO2ENERGY?

Renewability of biomass makes it an attractive source of energy

About 10% of arable lands across Europe seems to be marginal

About 100 million to 1 billion ha of marginal lands are theoretically available for production worldwide

About 800 thousand km[2] of soils in Europe are considered polluted or potentially polluted in that 30% with heavy metals



Use of land for biomass production should not compete with its use for food production

Some energy crop species demonstrate potential for heavy metal removal

Scientifical &Technological Objective

Selection of optimal energy crop species suitable for both biomass production and phytoremediation purposes of HMC sites and found the possible ways of residues utilization after biomass gasification

Four pre-selected species (energy crops) were used for plot experiments

Miscantus
Miscanthus x *gigantheus*

Virginia mallow
Sida hermaphrodita

Cordgrass
Spartina pectinata

Switchgrass
Panicum virgatum

They demonstrate promissing performance in terms of biomass yield and metal uptake

Expected results:

- obtain information which energy crop species are optimal in terms of biomass yield, robustness and relative site management goal,
- develop a simple guidance on phytoremediation driven energy crop production to be used in HMC sites management practice.

Test sites for plot experiments

Polish site :
Bytom,
Silesia Region

- Contaminated arable land
- Management goal: remove HMC contamination
- Old (4 year) plantations + new plots established for the selected plant species

German site:
Biotop Schladitz, Leipzig,
Saxony

- Post industrial site (former sewage sludge disposal site)
- Management goal: restore the site for an economic use
- New plots established for the selected plant species

Polish test site characteristics

Property	Value
pH (1 : 2.5 soil/KCl ratio)	6.79 ± 0.01
Electrical conductivity (μS/cm)	127 ± 0.002
Organic matter content (%)	4.0 ± 0.03
Sand (1 – 0.05 mm), %	28
Silt (0.05 – 0.002 mm), %	56
Clay (< 0.002 mm), %	16
Total heavy metal concentration (extraction with aqua regia)	
Pb (mg kg^{-1})	547.0 ± 27.92
Cd (mg kg^{-1})	20.84 ± 1.17
Zn (mg kg^{-1})	2174 ± 103
$CaCl_2$ extractable metal fraction [a]	
Pb (mg kg^{-1})	0.39 ± 0.03 (0.07) [b]
Cd (mg kg^{-1})	1.20 ± 0.03 (5.76) [b]
Zn (mg kg^{-1})	46.52 ± 1.51 (2.13) [b]

Values represent mean of three replicate samples ± SE

[a] – extraction with 0.01 M $CaCl_2$

[b]– in parentheses percentages of total metal concentrations are presented

German test site characteristics

Property	Value
pH (1 : 2.5 soil/KCl ratio)	6.37 ± 0.010
Electrical conductivity (µS/cm)	797 ± 0.040
Organic matter content (%)	32.95 ± 13.04
Sand (1 – 0.05 mm), %	58
Silt (0.05 – 0.002 mm), %	19
Clay (< 0.002 mm), %	23
Total heavy metal concentration (extraction with aqua regia)	
Pb (mg kg^{-1})	574.8 ± 24.68
Cd (mg kg^{-1})	31.20 ± 1.98
Zn (mg kg^{-1})	3592 ± 146
$CaCl_2$ extractable metal fraction [a]	
Pb (mg kg^{-1})	BDL
Cd (mg kg^{-1})	0.280 ± 0.05 (0.89) [b]
Zn (mg kg^{-1})	16.24 ± 1.01 (0.45) [b]

Values represent mean of three replicate samples ± SE

[a] – extraction with 0.01 M $CaCl_2$

[b]– in parentheses percentages of total metal concentrations are presented

Plot experiments design

Plots setting:

- on the area about 0.25 ha 20 plots (4x4 m) with a buffer zone of 4 were established,
- appropriate soil preparation for plant seedlings,
- seedlings to be planted on each experimental site (miscanthus, cordgrass, switchgrass, virginia mallow),

Experimental options:

I. C - control (no treatment),

II. NPK - standard fertilization, applied directly to the soil once before planting,

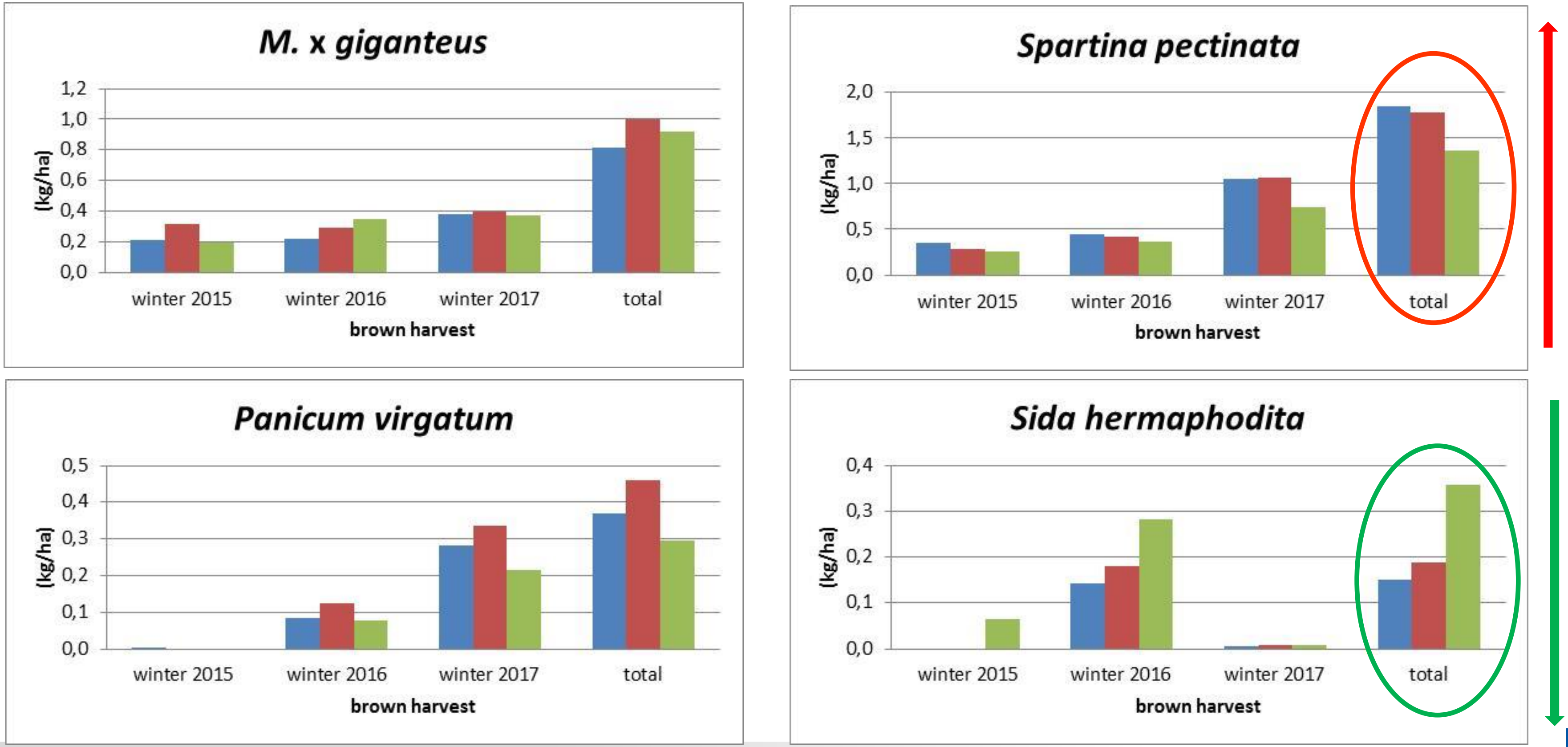
III. INC - commercial microbial inoculum applied on seedlings roots before plantation and on the leaves as aerosol in the middle of every month during the growing seasons (from May to September 2014, 2015, 2016),

Materials and methods

- **plant production potential** (quantity and quality), crop and yield development,
- **soil analyses:** bulk density, pH, electrical conductivity, organic matter, organic carbon, total concentration (*aqua regia* extraction) of Pb, Cd, Zn, N, P, K, Ca, Mg, Fe, S and bioavailable fraction ($CaCl_2$ extraction) of Pb, Cd and Zn,
- **plant analyses** (autumn and winter harvest): content of macronutrients and contaminants (Pb, Cd, Zn),
- **biomass gasification quality**: biomass, ash and tar content - mineral content - N, P, K, Mg, Ca, content of critical elements (Cl, Si), heavy metal content (Pb, Cd, Zn)
- **plant physiological parameters** (for Katowice trial): photosynthesis rate, transpiration rate, stomatal conductance, chlorophyll, flavonoids and anthocyanins content, leaf index area (LAI),

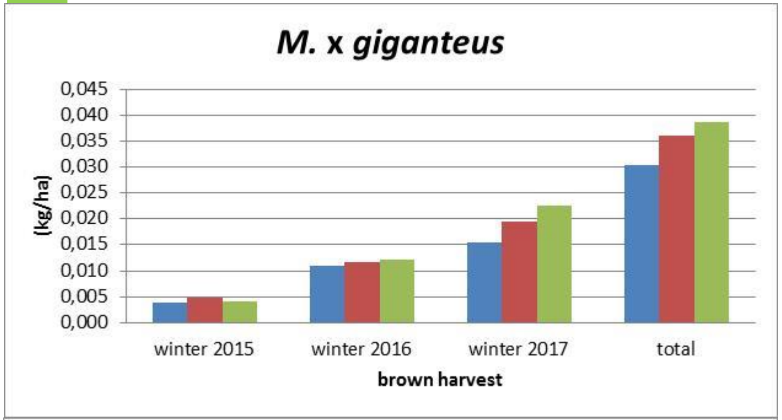
Pb extraction – brown harvest – contaminated arable land (kg/ha/year)

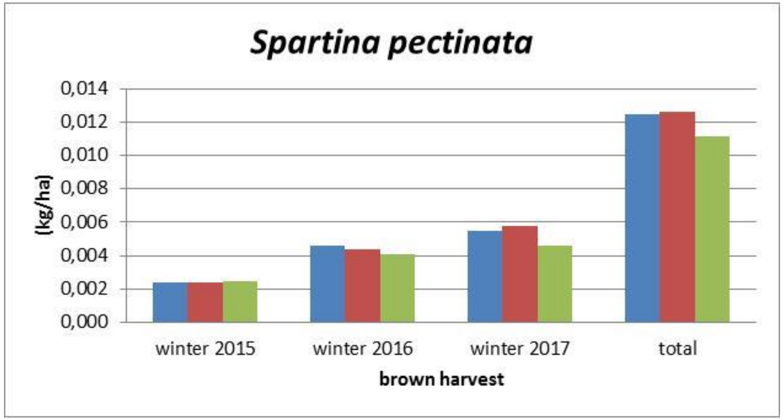
CONTROL
NPK
INOCULUM

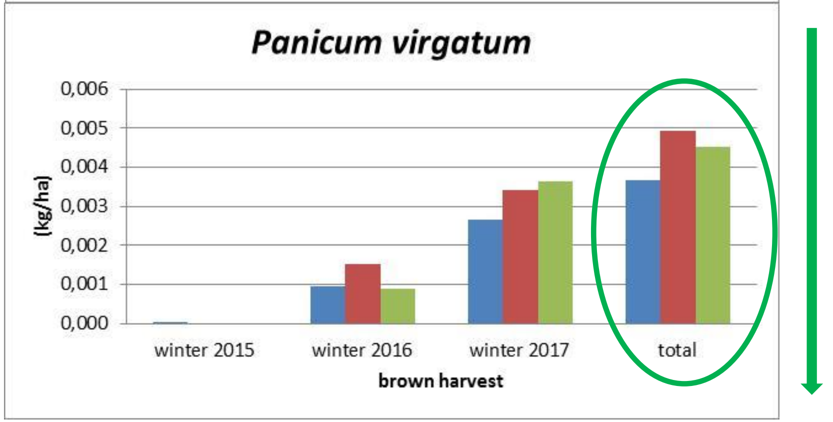


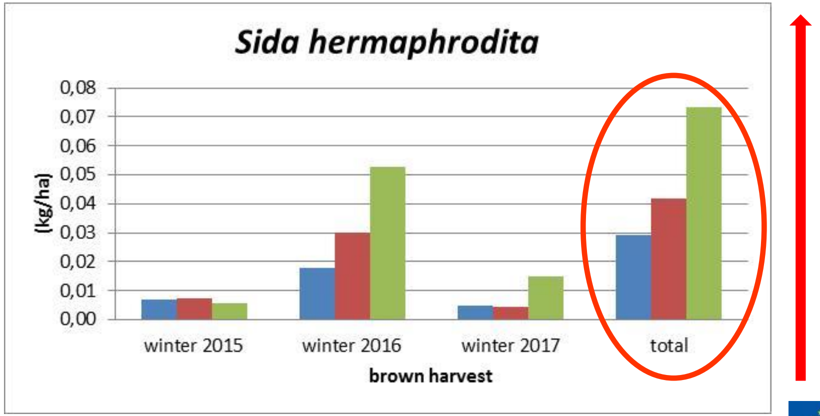
Cd extraction – brown harvest – contaminated arable land (kg/ha/year)

CONTROL
NPK
INOCULUM



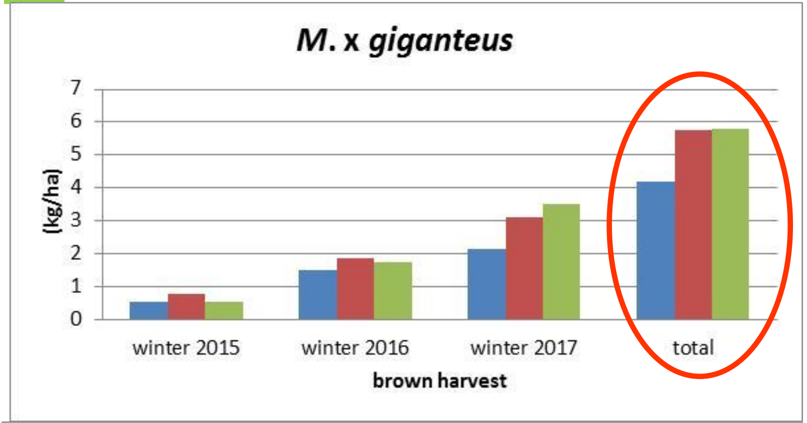


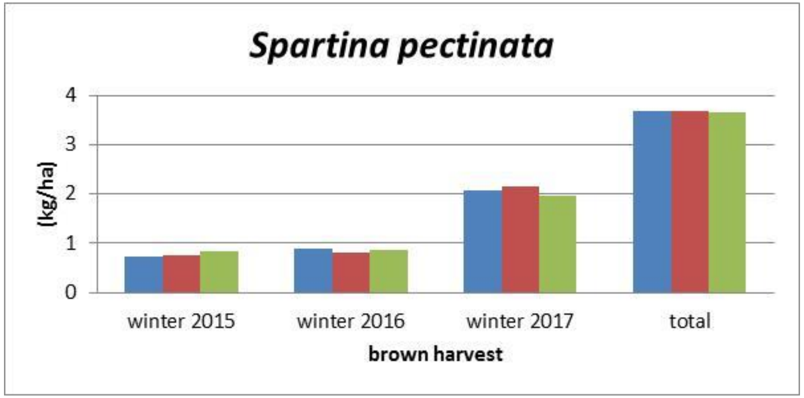


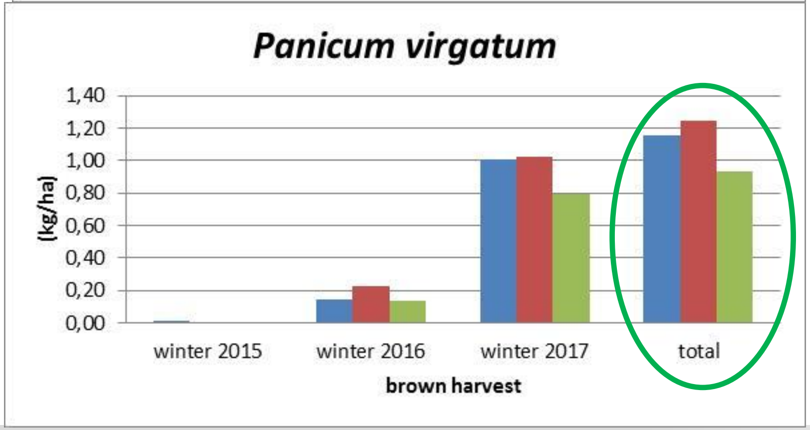


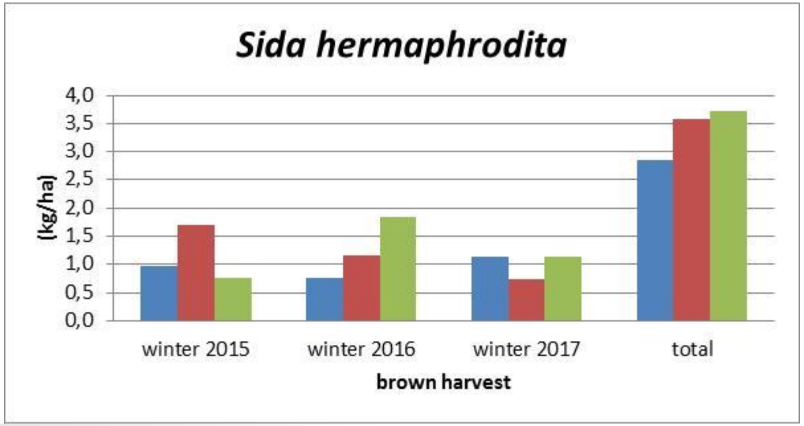
Zn extraction – brown harvest – contaminated arable land (kg/ha/year)

CONTROL
NPK
INOCULUM









Environmental Pollution
Volume 128, Issue 3, February 2004, Pages 373–379

Phytoextraction crop disposal—an unsolved problem

A Sas-Nowosielska[a], R Kucharski[a], E Małkowski[b], M Pogrzeba[a], J.M Kuperberg[c], K Kryński[a]

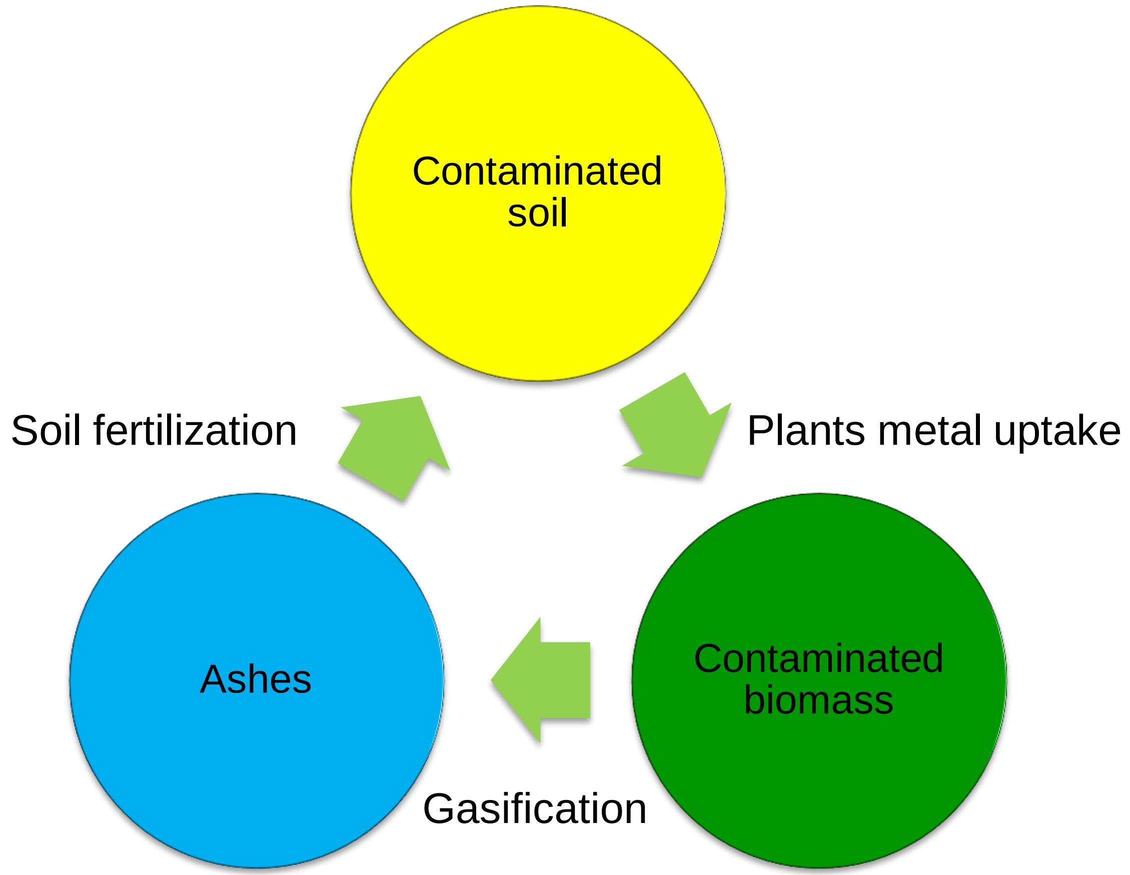
Process	Transport costs (EUR/t/km)	Cost of processing (EUR/t)	Advantages	Disadvantages
Incineration	1-2	180-220	Metals recovery? Significant reduction of biomass	None
Direct disposal as hazardous waste	1-2	136-1135	Time effectiveness	High cost, disposal sites limitation, slow reduction of biomass, metals leaching
Ashing	1-2	Not available	Metals recovery. Significant reduction of biomass	No technology
Liquid extraction	1-2	Not available	Metals recovery	No technology

Distribution of heavy metals in gasification residues – tars and ashes

Experimental variant	Tars (mg kg $^{-1}$ d.w.)			Ashes		
	Pb	Cd	Zn	Pb	Cd	Zn
MG control	51.2	<0.60	39.6	1342	<0.60	3308
MG fertilization	12.4	<0.60	19.2	947	<0.60	3603
MG inoculum	64.4	5.17	221	1164	<0.60	2909
SH control	30.5	<0.60	54.5	171	<0.60	2471
SH fertilization	111	9.3	278	81	<0.60	5805
SH inoculum	89.1	5.95	185	296	<0.60	2370
SP control	91.1	3.88	225	599	<0.60	2511
SP fertilization	71.1	1.55	174	584	<0.60	3003
SP inoculum	61.5	3.78	177	477	<0.60	1918

from 10- to 20-times higher content of Pb and Zn in ashes in comparision to tars

Energy crop production cycle at contaminated areas



Residues management – options of ashes used after gasification

- fertilizer in agriculture:

Pb – 140 (mg kg^{-1})

Cd – 5 (mg kg^{-1})

(Decision of Polish Ministry of Agriculture and Rural Development, June 2008)

- amendment improving soil quality at post-industrial areas:

Pb – 1000 (mg kg^{-1})

Cd – 25 (mg kg^{-1})

Zn – 3000 (mg kg^{-1})

(Decision of the Ministry of the Environment on Sewage Sludge used for non-agricultural land reclamation, July 2010)

Ash composition after gasification process

Variants		Pb	Cd	Zn	P	Fe	K/K_2O	Ca/CaO	Mg/MgO
		(mg kg^{-1})					(% w/w)		
Poland	MG control	1342	<0.60	3308	2449	9555	2.46	2.90	0.794
	MG fertilization	947	<0.60	3603	2320	5073	2.63	3.99	0.778
	MG inoculum	1164	<0.60	2909	4115	6379	3.07	2.62	0.766
	SH control	171	<0.60	2471	4139	2050	2.96	12.80	2.09
	SH fertilization	81	<0.60	5805	3957	3265	3.63	17.10	2.30
	SH inoculum	296	<0.60	2370	2114	1178	2.76	13.10	1.78
	SP control	599	<0.60	2511	1917	3058	3.29	4.77	0.382
	SP fertilization	584	<0.60	3003	2057	4424	2.51	4.06	0.381
	SP inoculum	477	<0.60	1918	1596	2596	2.63	3.32	0.258
Germany	SH control	<6.60	<0.60	502	7490	799	0.578	27.50	1.06
	SH fertilization	11.10	<0.60	629	10305	929	0.608	23.80	1.50
	SH inoculum	<6.60	<0.60	539	1629	74	1.88	14.20	0.851

Na < 83 mg/kg

Fertilizer in agriculture (green) — Brownfield reclamation (grey)

Conclusions

- **The main factor determined plant metal uptake is level of bioavailability of heavy metals (HM) in soil (soil solution),**

- **High bioavailability of metals (especially Cd and Zn) influence on highest plant uptake of HM in all tested species at Bytom site (Polish case study) compared to Leipzig site (German case study),**

- **The highest Pb uptake was found in *Panicum virgatum*, while the highest Cd and Zn content were assessed for *Panicum virgatum* and *Sida hermaphrodita* grown at Polish arable land contaminated with HM,**

- **The lowest concentration of heavy metals were found in *Spartina pectinata* regardless of the level of soil HM bioavailability. It means that this plant can be used as a „save biomass" produced on HM contaminated soils, but level of HM extraction for this plant was high due to high biomass production,**

Conclusions

- **Significantly higher content of Cd and Zn in plant biomass was found after 2nd growing season for brown harvest of all tested species from sewage sludge deposit site, in comparison to green harvest,**
- **For contaminated arable land, such relations were assessed only for Pb and Cd in *Sida hermaphrodita* and *Spartina pectinata*,**
- **results from brown harvest showed high potential of:**
  (i) Pb phytoextraction by *S. pectinata* (up to 1 kg/ha/year),
  (ii) Cd phytoextraction by *S. hermaphrodita* (up to 0.05 kg/ha/year),
  (iii) Zn phytoextraction by *M.* x *giganteus* (up to 3 kg/ha/year) and *S. pectinata* (up to 2 kg/ha/year),
- **It is necessary to harvest and disposal in the safe way the biomass after the first growing season (even if the yield is low) on HM contaminated lands because of high HM uptake by plants,**

Conclusions

- **The key findings from the gasification tests performed so far demonstrated that the obtained gaseous fuel could be used to produce energy in different types of installations,**
- **Gasification process gives the opportunity to assess the quantity of heavy metals which goes to gas phase or to gasification solid residues - ashes or tars,**
- **The contents of nutrient components in the ashes of the biomass after gasification process is much lower than in the case of ash resulting from the combustion process,**
- **Analyzing the post processing residues quality, including the content of heavy metals, macro- and microelements, the requirements for using them as fertilizer in agriculture have been met only for ashes after *Sida hermaphrodita* gasification,**
- **Nevertheless, ashes after gasification process (from all experimental options for *Sida hermaphrodita* and *Spartina pectinata*) could be used as an amendment improving soil quality at post-industrial areas.**

Plants growth in 2017 - Polish site

Publications

Pogrzeba M, Rusinowski S, Sitko K, Krzyżak J, Skalska A, Małkowski E, Ciszek D, Werle S, McCalmont JP, Mos M, Kalaji HM, 2017. Relationships between soil parameters and physiological status of *Miscanthus* x *giganteus* cultivated on soil contaminated with trace elements under NPK fertilisation vs, microbial inoculation, Environmental Pollution, 225,163-174.

Pogrzeba M, Rusinowski S, Krzyżak J, 2017. Macroelements and heavy metals content in *Panicum virgatum* cultivated on contaminated soil under different fertilization. International Journal Agriculture & Forestry, Vol, 63 Issue 1: 69-76, Podgorica, DOI: 10.17707/AgricultForest.63.1.08.

Werle S, Bisorca D, Katelbach-Woźniak A, Pogrzeba M, Krzyżak J, Ratman-Kłosińska I, Burnete D, 2017. Phytoremediation as an effective method to remove heavy metals from contaminated area - TG/FT-IR analysis results of the gasification of heavy metal contaminated energy crops. Journal of the Energy Institute, 90(3), 408-417.

Pogrzeba M, Krzyżak J, Rusinowski S, Werle S, Hebner A, Milandru A, 2018. Case Study on Phytoremediation Driven Energy Crop Production Using *Sida hermaphrodita*, International Journal of Phytoremediation, in press.

More info about Phyto2Energy

www.phyto2energy.eu

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PHYTOREMEDIATION POTENTIAL OF NOVEL SEED-BASED MISCANTHUS GERMPLASM CULTIVATED ON CONTAMINATED LAND: AN INTRODUCTION TO THE MISCOMAR PROJECT

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J. Krzyżak, S. Rusinowski,
J. Clifton-Brown, J.P. McCalmont,
A. Kiesel, A. Mangold, M. Mos

Partners

IETU
UNIVERSITY OF HOHENHEIM
PRIFYSGOL ABERYSTWYTH UNIVERSITY

Funding

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The National Centre for Research and Development
Federal Ministry of Education and Research
Department for Environment Food & Rural Affairs
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 652615.

Miscanthus biomass options for contaminated and marginal land: quality, quantity and soil interactions

PROJECT CONSORTIUM:

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UNIVERSITY OF HOHENHEIM

PRIFYSGOL ABERYSTWYTH UNIVERSITY

terravesta Energy, naturally.

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MAIN GOAL:
DEVELOP TECHNIQUES FOR BIOMASS PRODUCTION ON MARGINAL LAND IN EUROPE

- improving the understanding of land suitability for *Miscanthus* cultivation in Europe in general and especially on marginal land,
- developing concepts for sustainable integration of *Miscanthus* at farm and landscape levels,

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SPECIFIC OBJECTIVES

- investigate the field performance of novel, stress tolerant *Miscanthus* hybrids in comparison to the standard commercial clone *M.* x *giganteus* on economically marginal and heavy metal contaminated soils,
- quantify the impacts of *Miscanthus* production on soil parameters,
- identify utilisation options for biomass and study the impact of varying environmental conditions on potential *Miscanthus* end uses,
- develop concepts for the integration of Miscanthus into existing landscapes, crop rotations and farming systems,

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AREAS UNDER INTEREST

- soils contaminated with heavy metals

- marginal and fallow soils

- depleted soils from intensive agriculture

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MATERIALS AND METHODS

- **Plant:**
  promising near-to-market seed-based Miscanthus hybrids from IBERS' breeding program; control - the commercial standard M. x giganteus ,

photo from Terravesta Ltd., www.terravesta.com

- **Planting:**

  novel agronomy based on practices developed by Terravesta Ltd.

- **Three locations (under three different climates):**

1. heavy metal contaminated soils - Katowice, Southern Poland (dry continental),

2. Nutrient depleted, intensive arable soils – Lincolnshire (temperate)

3. high clay content, waterlogged soils – Unterer Lindenhof, Southern Germany (wet continental)

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Novel, seed based inter-species Miscanthus hybrids

- 7 novel hybrids tested across three marginal sites and compared to *M.* x *giganteus,*
- Developed under IBERS' breeding programme from wild collections across Asia,
- All material produced under CBD rules with full traceability and agreed profit sharing with donor countries following commercialisation,
- Hybrid breeding allows crop lines to be tailored to climate, soils and end-uses,
- Seed based propagation allows far greater scope to scale up biomass production compared to clonal rhizome propagation,

- https://www.youtube.com/watch?v=3a4aaYz71TU

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MATERIALS AND METHODS

- plant production potential (quantity and quality), crop and yield development,
- soil analyses: bulk density, pH, electrical conductivity, organic matter, organic carbon, total concentration (aqua regia extraction) of Pb, Cd, Zn, N, P, K, Ca, Mg, Fe, S and bioavailable fraction ($CaCl_2$ extraction) of Pb, Cd and Zn,
- plant analyses (autumn – green and winter – brown harvest): content of macronutrients and contaminants (Pb, Cd, Zn),
- combustion and anaerobic digestion quality: ash content, mineral content (N, P, K, Mg, Ca), content of critical elements (Cl, Si), ash melting behaviour, substrate-specific biogas and methane yield (including methane content of the biogas), fibre content (hemicellulose, cellulose and lignin), protein content,
- plant physiological parameters (for Katowice trial): photosynthesis rate, transpiration rate, stomatal conductance, chlorophyll, flavonoids and anthocyanins content, leaf index area (LAI),

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LOCATION OF THE SITES

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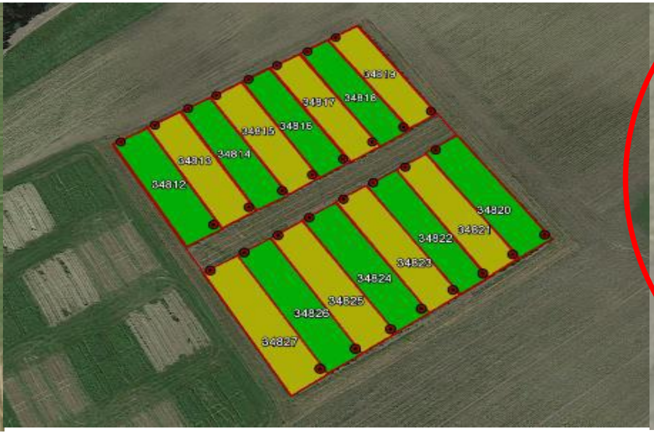
EXPERIMENTS RANDOMISATION

UNITED KINGDOM

GERMANY



POLAND

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POLISH TEST SITE

- contaminated arable land
- 4 hybrids + *M.* x *giganteus* as a control

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POLISH TEST SITE CHARCTERISTIC

Property	Value
pH (1 : 2.5 soil/KCl ratio)	6.47 ± 0.03
Electrical conductivity (μS/cm)	90.63 ± 3.32
Organic matter content (%)	5.00 ± 0.11
Sand (1 – 0.05 mm), %	28
Silt (0.05 – 0.002 mm), %	56
Clay (< 0.002 mm), %	16
Total heavy metal concentration (extraction with aqua regia)	
Pb (mg kg^{-1})	527 ± 21.0
Cd (mg kg^{-1})	19.9 ± 1.0
Zn (mg kg^{-1})	2769 ± 301
$CaCl_2$ extractable metal fraction [a]	
Pb (mg kg^{-1})	0.03 ± 0.01 (0.005) [b]
Cd (mg kg^{-1})	1.35 ± 0.05 (6.78) [b]
Zn (mg kg^{-1})	84.0 ± 5.6 (3.03) [b]

Values represent mean of three replicate samples ± SE

[a] – extraction with 0.01 M $CaCl_2$

[b] – in parentheses percentages of total metal concentrations are presented

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CONCLUSIONS AFTER 2nd GROWING SEASON

- not all tested seed-based *Miscanthus* hybrids were able to survive their first Polish winter, despite being not particularly harsh with only occasional freezing. However the lack of snow to provide an insulating blanket for the soil likely played a significant role in this,
- 5 to 10 times higher concentrations of Pb were found in the biomass of the new *Miscanthus* hybrids collected in Autumn in comparison to *M.* x *giganteus,*
- HM content assessed in the brown harvest (collected after winter ripening) were from 3 to 30-times higher compared to the green harvest (collected at the end of the growing season) , particularly for the first growing season and for Pb,
- all tested seed-based *Miscanthus* hybrids accumulated lower levels of Cd and Zn compared to *M.* x *giganteus*, even where the bioavailable fraction of these metals in the soil was similar between plots.

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Welcome to the MISCOMAR project!

Our project: Miscanthus biomass options for contaminated and marginal land: quality, quantity and soil interactions - MISCOMAR is a joint initiative of an international consortium under the flag of FACCE SURPLUS (Sustainable and Resilient agriculture for food and non-food systems) ERA-Net Cofund, formed in collaboration between the European Commission and a partnership of 15 countries in the frame of the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI).

Latest News

- MISCOMAR Project at International Bioenergy Conference in Manchester
- Presentation of the MISCOMAR Project
- Visit to the Institute of Biological, Environmental and Rural Sciences (IBERS) of Aberystwyth University
- Visit to Lincolnshire's Miscanthus experimental fields
- Article : Development of techniques for biomass production on marginal land in Europe

www.miscomar.eu

https://www.researchgate.net/project/MISCOMAR

https://pl.linkedin.com/in/miscomar-project-460a3a128

FACCE SURPLUS SUSTAINABLE AND RESILIENT AGRICULTURE FOR FOOD AND NON-FOOD SYSTEMS

The National Centre for Research and Development

Federal Ministry of Education and Research

Department for Environment Food & Rural Affairs

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 652615.

Thank you for your attention

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