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

Possibility of using energy crops for phytoremediation of heavy metals contaminated land – three years experience

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

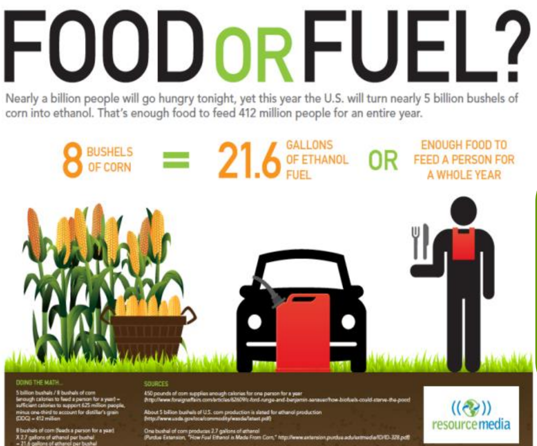
Why PHYTO2ENERGY?

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.

Miscanthus *(Miscanthus* x *gigantheus)*

- originates from East Asia
- natural triploid hybrid between *M. sinensis* and *M. sacchariflorus*
- propagated by rhizomes (20 000 plants/ha)
- easy to grow and harvest
- gives a high dry-matter yield (25-30 t d.w./ha/year)
- plant is soil pH tolerant
- plantation can be used for 15-25 years
- one year seedlings are very sensitive for low temperature
- can be grown on different soil types

Virginia mallow *(Sida hermaphrodita)*

- originates form South America
- low soil and climate requirements
- deep root system
- good tolerance of low and high temperatures
- can be grown on different soil types
- high decrease of harvesting biomass due to lack of water
- plantation can be used for 15-20 years

Switchgrass *(Panicum virgatum)*

- originates from North America
- can grow on moderately salt soil
- produces magnificent, green or gray-green clumps, reaching mostly 1-2 m high
- good tolerance for alkaline soil
- comparable to the calorific value of wood with a lower moisture content
- sustainability is characteristic for this species
- biomass production:

  1st year - 5-8 t d.w./ha

  2nd year - 14-18 t d.w./ha

  3rd year - 16-24 t d.w./ha

Cordgrass *(Spartina pectinata)*

- originates from North America
- forming extensive and loose clumps, grows to about 2 m,
- good adaptation to different environmental conditions
- ability to protect soil from erosion
- lack of seeds on the market
- mineral fertilization needed after first growing season

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),

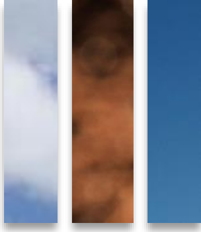
II. NPK - standard fertilization, applied directly to the soil once before planting,

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:** pH, electrical conductivity, organic matter, 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),
- **plant physiological parameters** (for Katowice trial): photosynthesis rate, transpiration rate - for both trials and stomatal conductance, chlorophyll, flavonoids and anthocyanins content, leaf index area (LAI) - for Katowice trial ,

M. x *giganteus* – differences in HM content depending on time of harvest and HM site contamination



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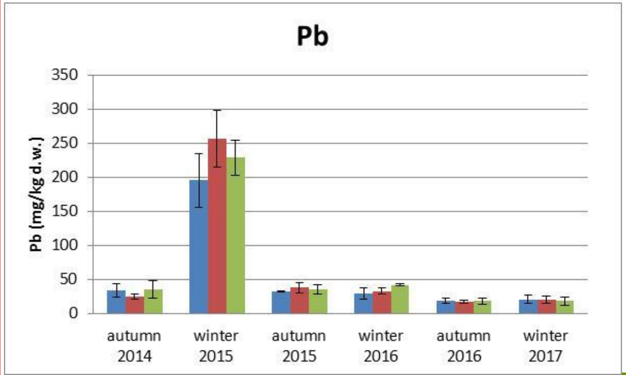
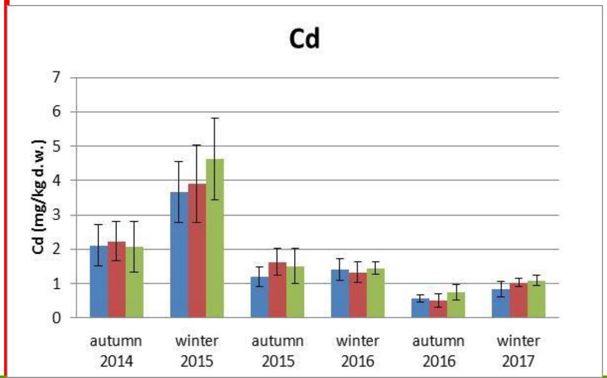
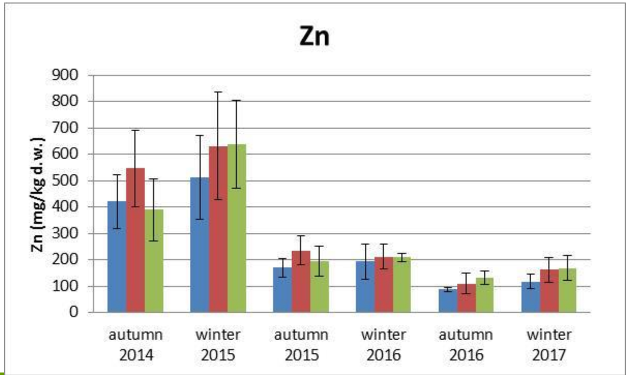
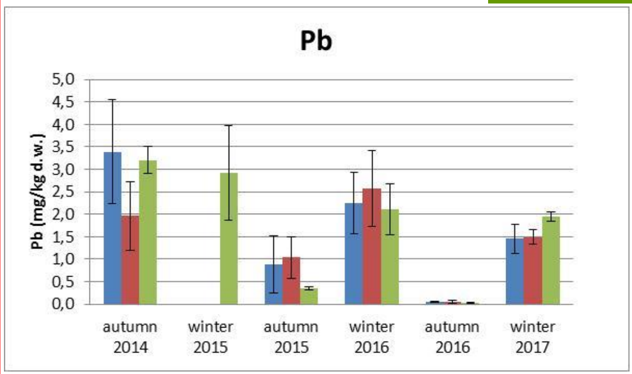
contaminated arable land – BYTOM, POLAND

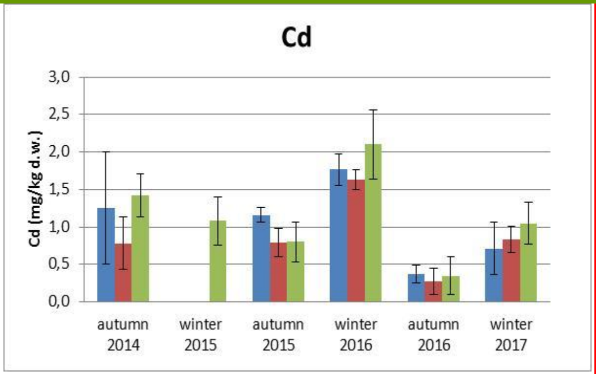


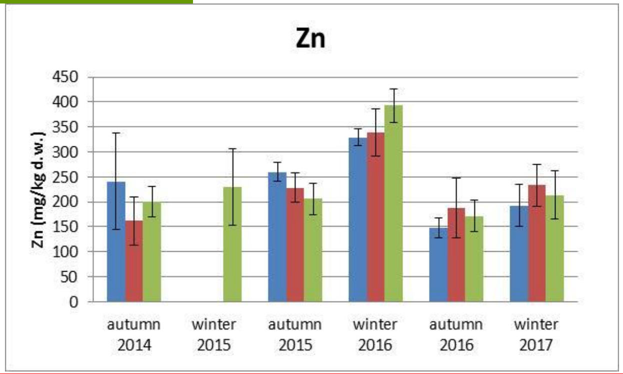




post industrial site – LEIPZIG, GERMANY







Spartina pectinata – differences in HM content depending on time of harvest and HM site contamination

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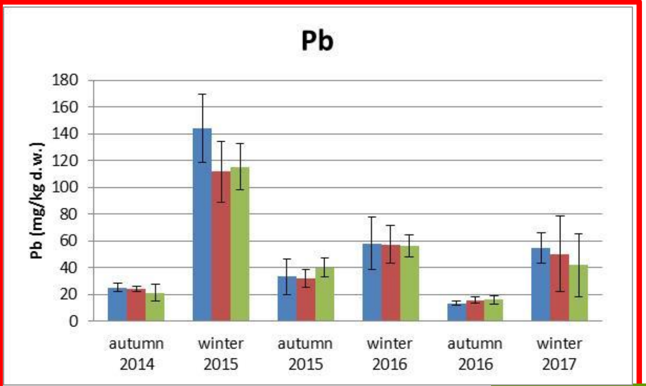

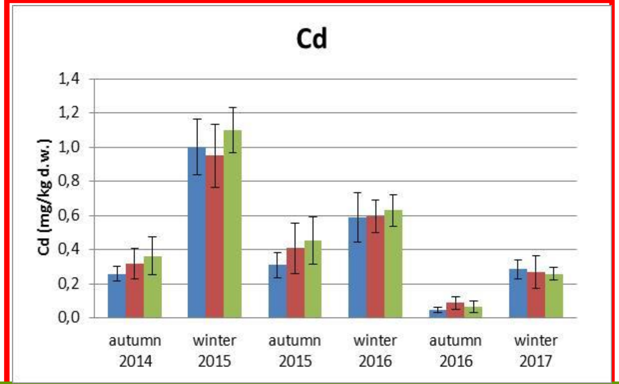

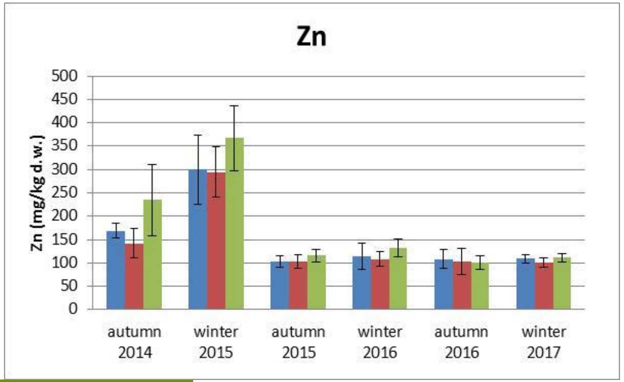

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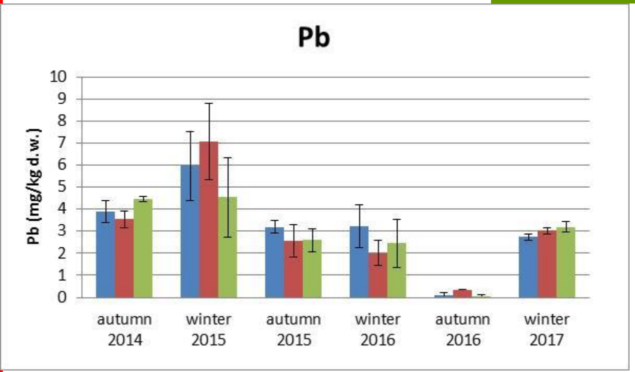

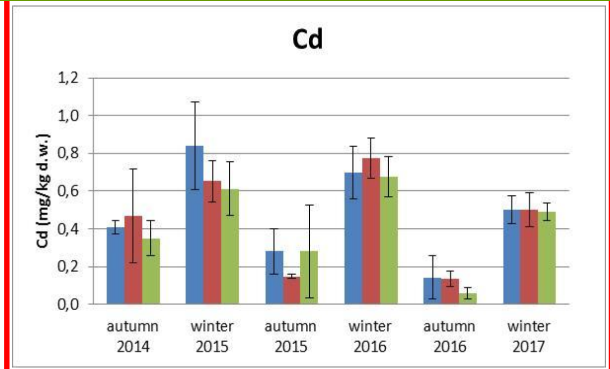

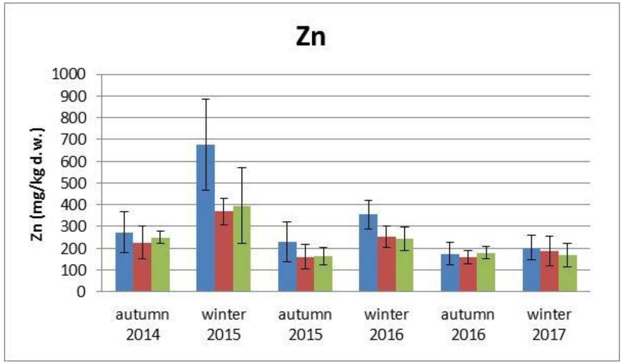

Panicum virgatum – differences in HM content depending on time of harvest and HM site contamination

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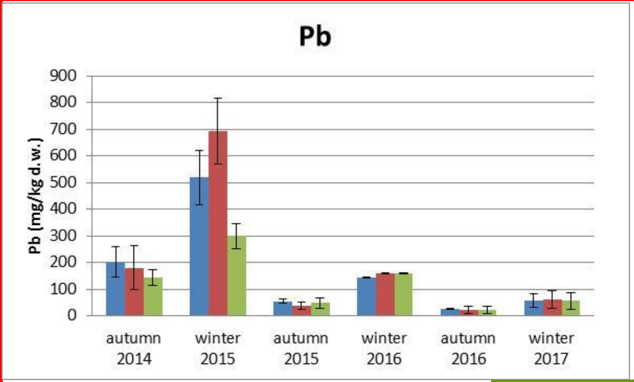
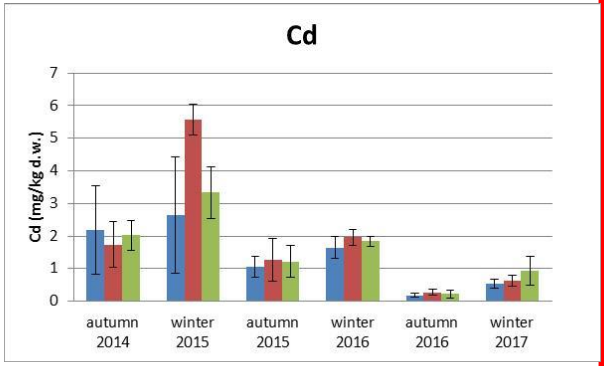
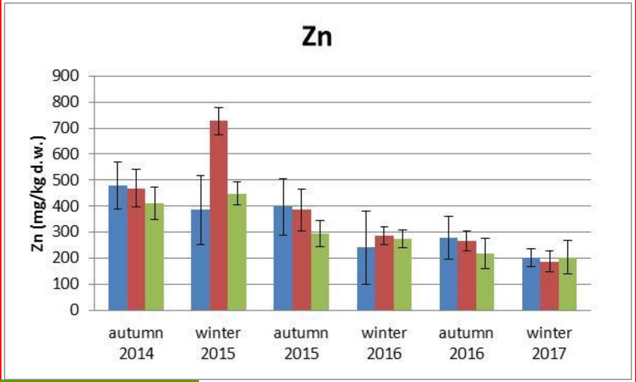
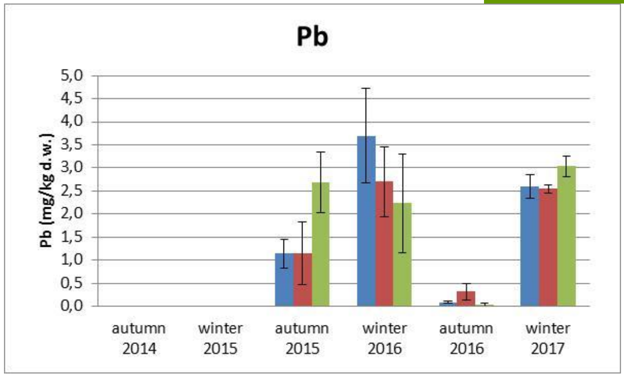
contaminated arable land – BYTOM, POLAND

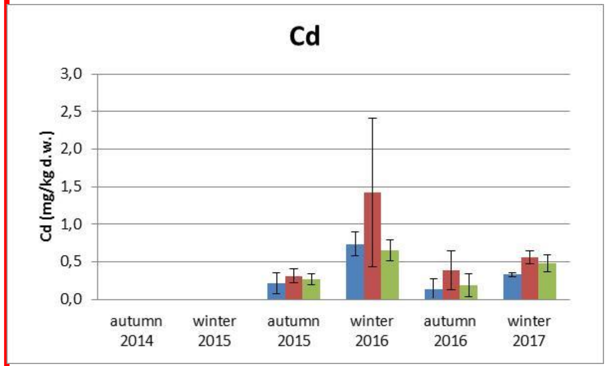


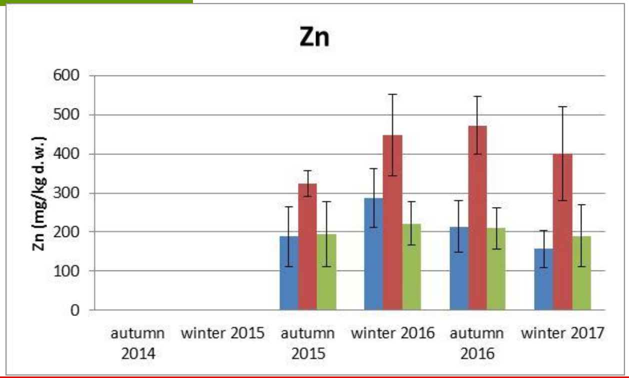




post industrial site – LEIPZIG, GERMANY







Sida hermaphrodita – differences in HM content depending on time of harvest and HM site contamination

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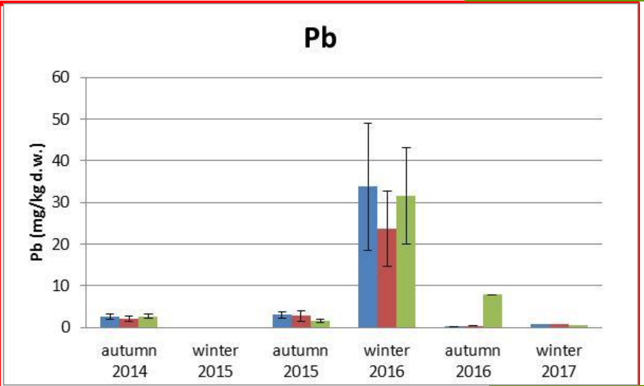
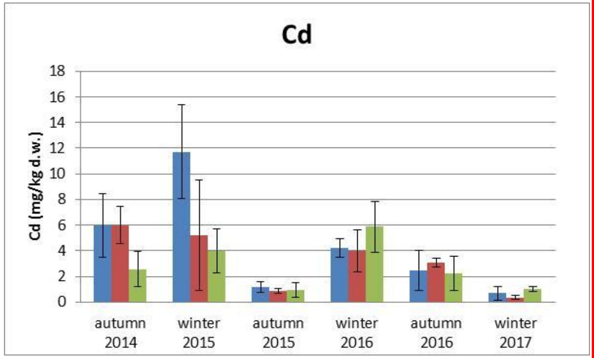
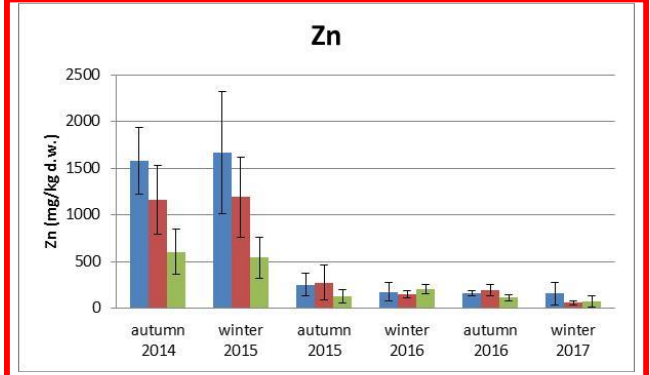
contaminated arable land – BYTOM, POLAND







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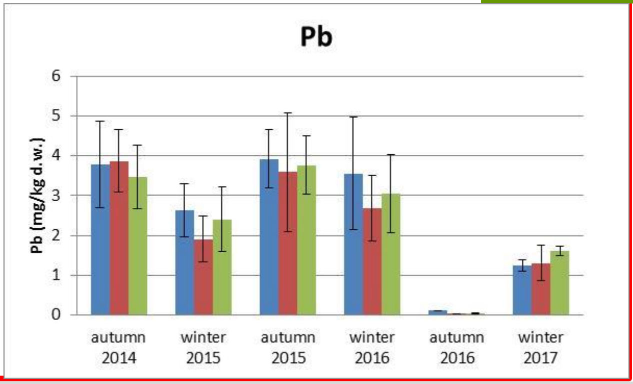

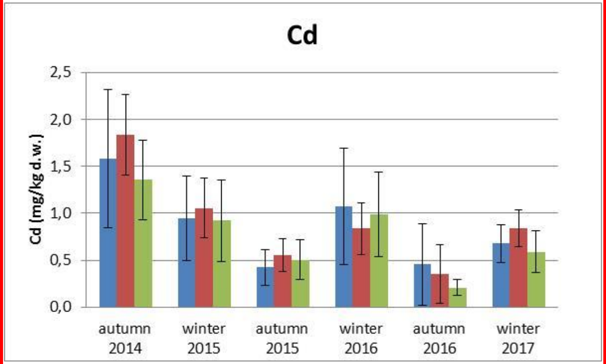

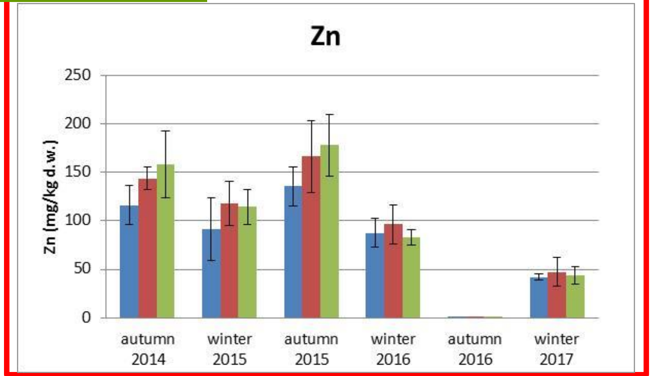

Pb extraction – brown harvest – contaminated arable land (kg/ha/year)

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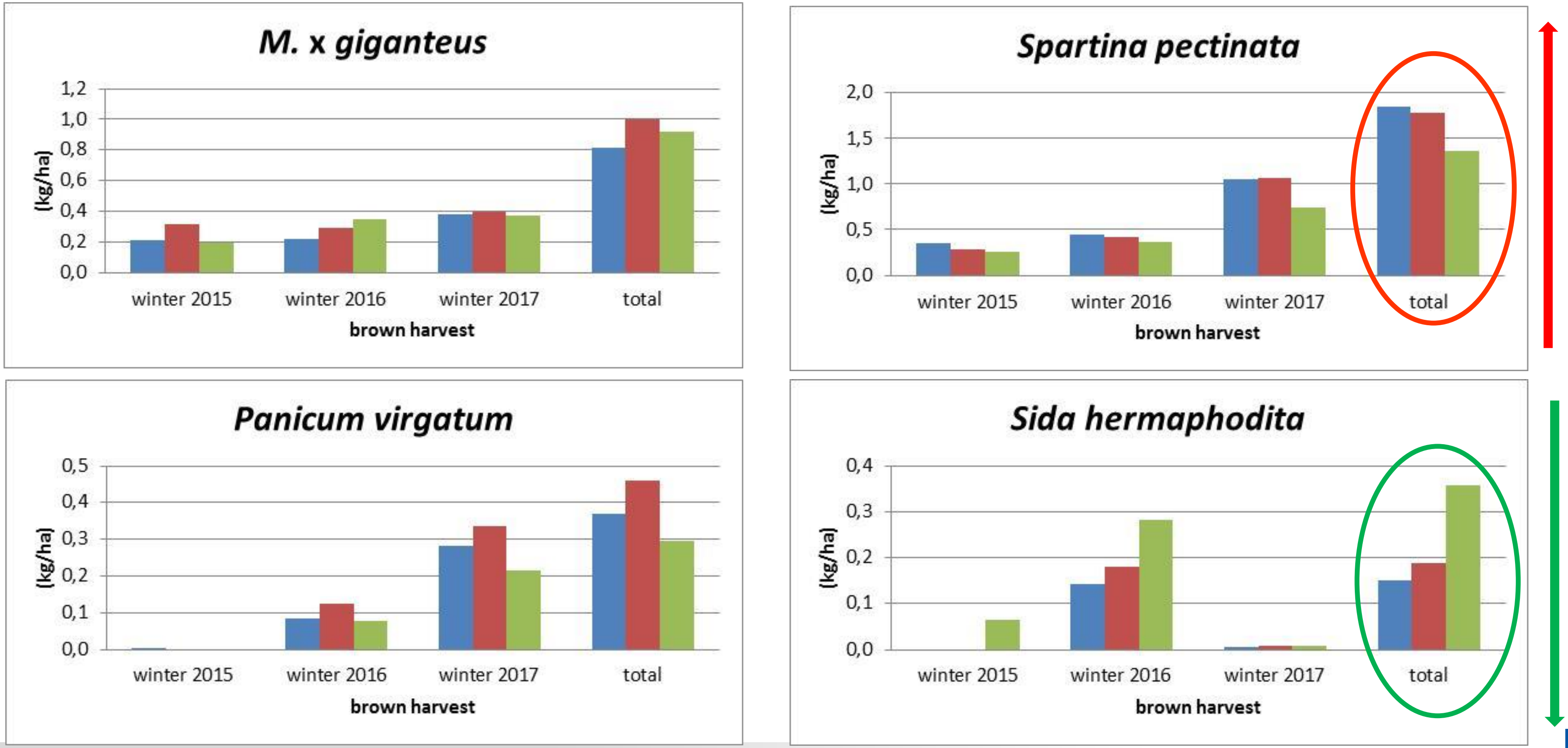

Cd extraction – brown harvest – contaminated arable land (kg/ha/year)

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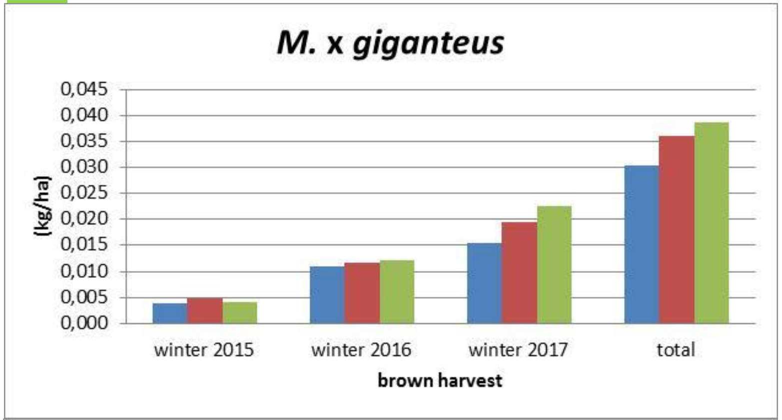

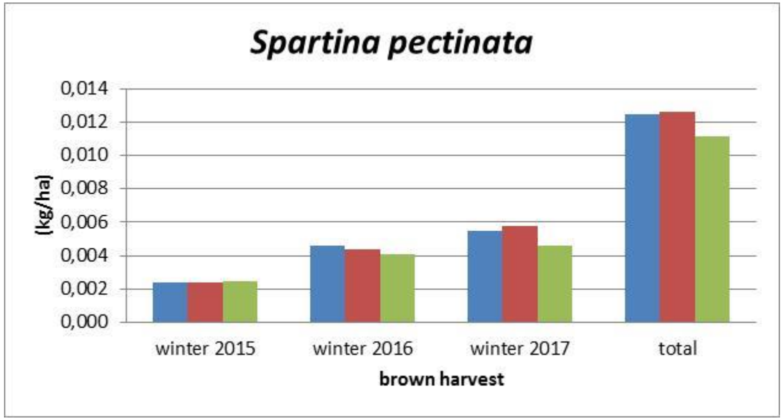

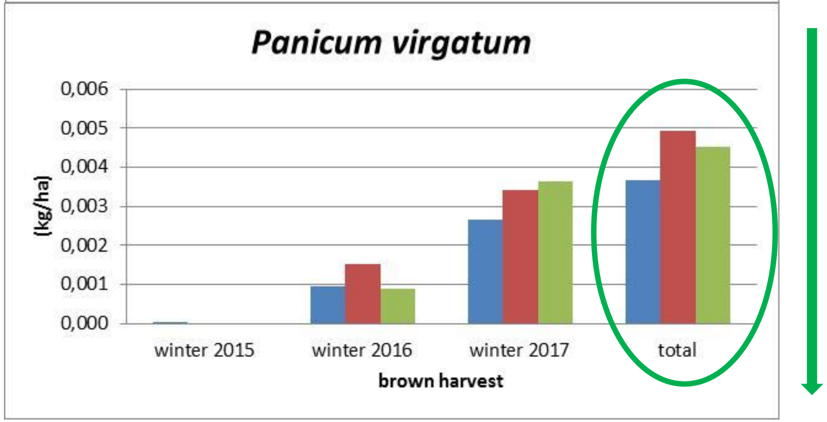

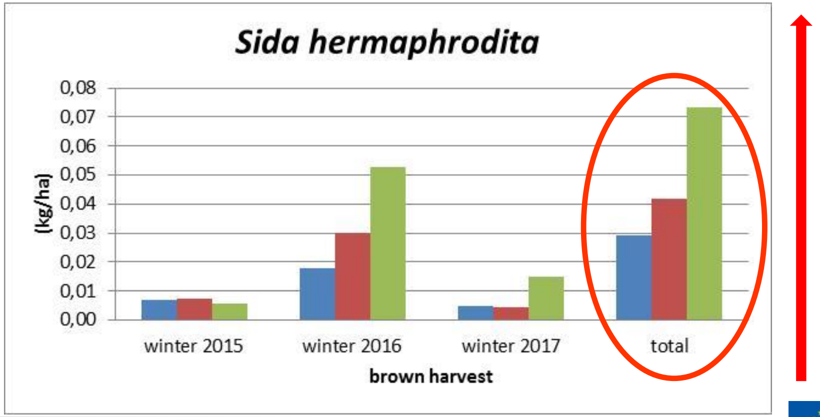

Zn extraction – brown harvest – contaminated arable land (kg/ha/year)

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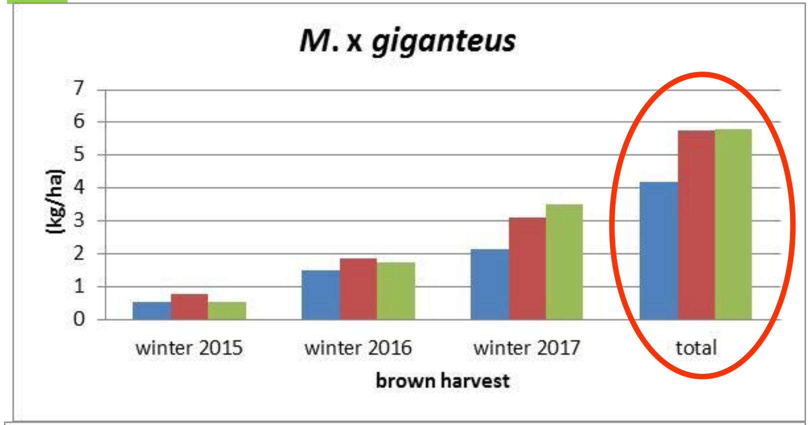

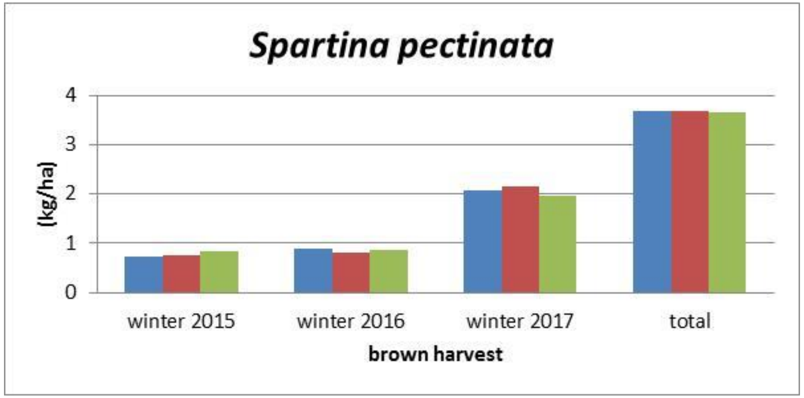

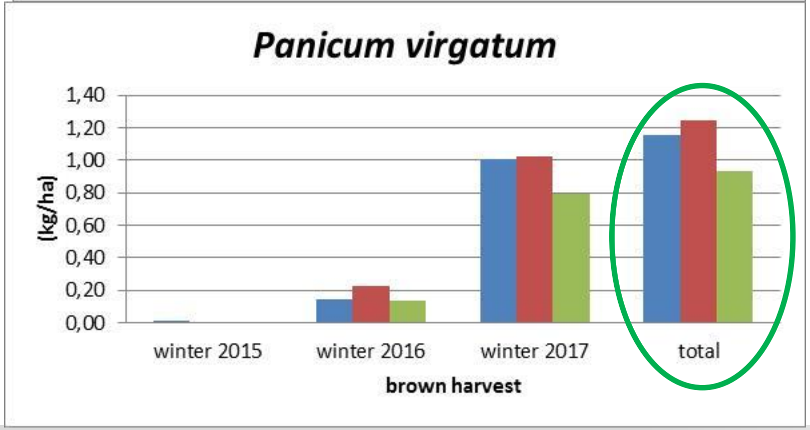

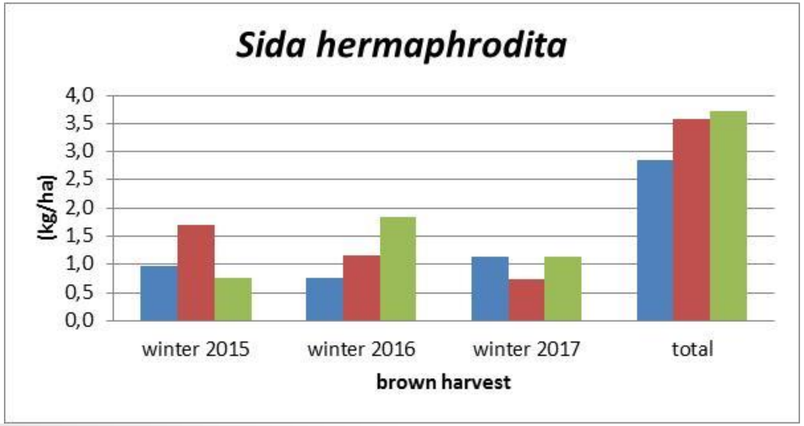

Conclusions

- **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) determine highest plant uptake 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 „safe 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),

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Publications

Pogrzeba M, Krzyżak J, Rusinowski S, Werle S, Hebner A, Milandru A, 2017. Case Study on Phytoremediation Driven Energy Crop Production Using *Sida hermaphrodita*, International Journal of Phytoremediation, **in press**.

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.

Thank you for your attention

IETU

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