

Environmental hazards related to *Miscanthus x giganteus* cultivation on heavy metal contaminated soil

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Abstract. According to recent estimates reaching the target of a 20% share of renewable energy sources (RES) in the final energy balance in Poland by 2020 will result in the demand for more than 8 million tons of biomass, which, in turn, will entail the necessity of creating large-scale energy crop plantations. According to EU assumptions the most effective way to produce biomass for energy purposes is cultivation of energy crops in agricultural areas. It is particularly vital for Poland, because these areas constitute a relatively large part of the country (59%), 76% of them being used as farmlands. In Silesia, the most industrialized region of the country, 5-10% of agricultural soils are contaminated with cadmium, lead and zinc. The main objective of the presented study was to estimate the accumulation of heavy metals in the tissues of *Miscanthus x giganteus* grown on contaminated soils and calculate concentrations of Pb, Cd and Zn in crops. It was shown that the large intake of heavy metals by that species could cause high emissions of pollutants into the atmosphere during its improper combustion. As a side effect, winter harvesting led to the loss of even 30% of biomass. Plant residues (leaves) can be the source of pollution after decomposing and releasing metals back into the soil. Moreover, miscanthus leaves can be transferred by wind to the surrounding areas. It is very likely that ash coming from the combustion of contaminated biomass cannot be used as a fertilizer.

Key words: *Miscanthus x giganteus*, soil contamination, heavy metals

Introduction

The most efficient way for energy crop production is to grow plants on medium or low quality agricultural land. According to Ericsson et al. (2006), it is particularly applicable for Poland where relatively large percentage of the total area (59%) is occupied by agricultural lands. However, in Poland the arable land is also situated in contaminated regions, unsuitable for food production (Kucharski et al., 1994).

In the Silesian Voivodeship, 5 to 10% of agricultural soils are contaminated with cadmium, lead and zinc (Siebielec et al., 2008). This contamination is the legacy of mining and smelting industry of Zn, Pb and Cd ores located in these regions (Kucharski et al., 1994).

Cultivation of energy crops in contaminated agricultural areas might lead to excessive concentrations of metals in plant tissues and reemissions of contaminants into the atmosphere during the biomass improper combustion. Another issue is environmental risk resulting from high content of heavy metals (especially Cd) in combustion residues (Dembiras, 2005). Moreover,

harvesting of miscanthus may lead to the recontamination of soil due to leave residues falling to the surface (Pogrzeba et al., 2012).

It is estimated that achieving a 20% share of RES in the final energy balance in 2020 will result in the demand for more than 8 million tons of biomass, which, in turn, will entail the necessity of creating large-scale energy plantations. The selection of crops for biomass production for energy purpose should be conducted taking into account the soil and climate of the region and technical capabilities of farmers. Species for energy crop production should be characterized by: high biomass yield, low costs of production; broad adaptation to local environmental conditions (soil type, humidity, etc.) (Majtkowski, 2007).

Among the species of interest the most suitable is *Miscanthus x giganteus*, the acreage of which is still growing in Poland, reaching about 1800 ha. Miscanthus gives the highest yield (up to 30 t dm/ha) of high calorific value (18.5 MJ/kg dm), and the energy value of the biomass is twice as high as the one obtained from the

combustion of a willow (Abassi and Abassi 2010, El Bassam, 2010).

The goal of the presented study was to assess metal concentrations in miscanthus tissues and calculate the total amount of metals in crops when growing on moderately contaminated soil. Moreover, potential environmental hazards related to miscanthus cultivation in such areas were estimated.

Materials and Methods

The experimental plots with *M. giganteus* were located on the contaminated agricultural soil in Bytom (southern part of Poland, Silesian Voivodeship). Plots were established in the vicinity of a closed-down lead/zinc/cadmium ore mining and processing plant. The metallurgical complex was in operation for more than 100 years and had a significant impact on local soils. Recently, the land has been used for grain crops production.

The experimental field (0.25 ha) was divided into subplots (4x4 m) with a buffer zone of 6 m. The soil was tilled to the depth of 20 cm and 50 seedlings of *Miscanthus x giganteus* per subplot were planted (Fig. 1).



Fig. 1. View of *Miscanthus x giganteus* experimental plots

The experiment was performed in the years 2005-2011. After two years of plant cultivation (2007), shoots from 1 m² were collected in wintertime. The dried biomass was weighted and analyzed for Pb, Cd and Zn content. For the last two growing seasons (2010-2011) the loss of weight in the plant biomass (leaves fallen on the soil surface) were also assessed.

For site characterization three composite soil samples per subplot (from the depth of 0-20 cm) were collected and analyzed. Physical and chemical soil properties such as: soil texture, pH, EC, content of organic matter, total metal concentration (aqua regia extraction) and bioavailable fractions of metal concentration (CaCl₂ extraction) were analyzed.

Plant samples were dried at 70 °C and digested using concentrated nitric acid in a microwave system (MDS 2000, CEM, USA). Concentrations of metals both

in soil and plants were measured with flame atomic absorption spectrophotometry (Varian Spectra AA300) or by inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Varian, USA). Data reported in this paper was processed using the computer software Microsoft Excel and Statistica 10. Probability of 0.05 or less was considered to be statistically significant.

Results and Discussion

Physical and chemical soil properties are presented in Tab. 1. The soil was classified as silty-clay loam. Heavy metal concentrations in soil exceeded Polish limits for arable soil (Ministry of the Environment, 2002). The pH was almost neutral, followed by high concentration of organic matter (OM) and low electric conductivity (EC). Bioavailable forms of cadmium were high (5.76%), whereas bioavailability of Pb was relatively low (0.07%; Tab.1).

Table 1. Soil characteristics

Property	Value
pH (1 : 2.5 soil/KCl ratio)	6.79 ± 0.01
Electrical conductivity (µS/cm)	200 ± 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
<i>Total heavy metal concentration (extraction with aqua regia)</i>	
Pb (mg kg ⁻¹)	547.0 ± 27.92
Cd (mg kg ⁻¹)	20.84 ± 1.17
Zn (mg kg ⁻¹)	2174.5 ± 103
<i>CaCl₂ extractable metal fraction^a</i>	
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 CaCl₂

^b – in parentheses percentages of total metal concentrations are presented

Dry weight of the collected biomass from 1 m² ranged from 1.4 kg after the first time of harvesting to 3.92 kg for the last year. The obtained results confirm that miscanthus can produce even 30 tones of biomass per ha, which was also mentioned by El Bassam (2010).

The content of Pb in the aboveground parts of miscanthus is shown in Fig. 2a. Lead concentration in plant shoots was high, despite the low level of bioavailable forms of Pb in soil. Starting from 2009 a statistically significant decrease in the concentrations of Pb in plants was observed. Compared to Barbu et al. (2009; 2010) the Pb concentration in miscanthus shoots

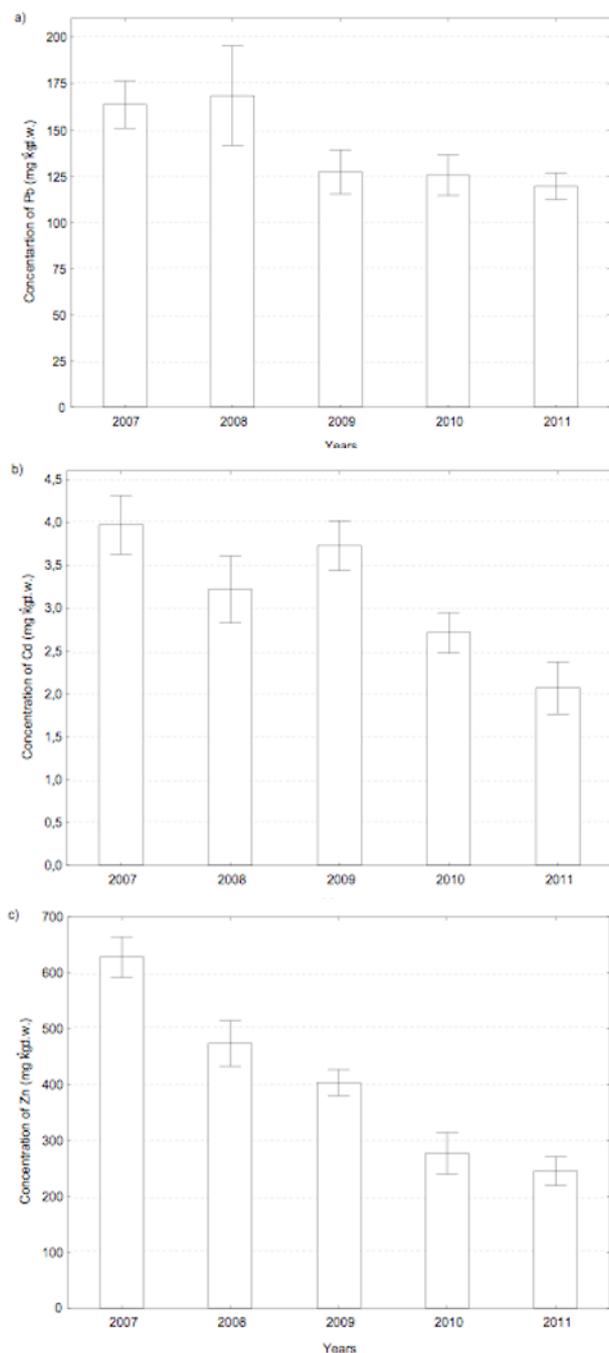


Fig. 2. Metal concentration in plant shoots (mg kg⁻¹ d.w.): a) Pb; b) Cd; c) Zn.

was 40 times higher when grown on the soil of a similar Pb content. The differences in the obtained results may be related to different levels of bioavailable forms of this metal in soil.

During the first three years of biomass collection (2007-2009) Cd concentrations were at similar levels (Fig. 2b). During the last two harvest periods lower Cd concentrations in the biomass were observed. The Cd concentrations were also two-fold higher than reported by other authors in the case of miscanthus growth on soil with a similar content of cadmium (Barbu et al., 2009, 2010). The study confirmed the positive correlation

between concentrations of heavy metals in the soil and their concentrations in the aerial parts of *M. giganteus*. The same relationship was observed by Arduini et al., (2006) in the hydroponics experiment, where a higher content of cadmium in an aqueous solution resulted in increased accumulation of that metal in the tissues of miscanthus.

During the 5-years plot experiment the content of Zn in the aboveground parts of miscanthus decreased, reaching the lowest value in the last harvest (Fig. 2c). The highest concentrations of Zn (630 mg kg⁻¹ d.w.) were found in the biomass from the first harvest. Meers et al. (2010) reported that maize (a monocotyledonous plant as miscanthus) cultivated for energy purposes accumulate 4 to 10-fold lower amount of Zn in the biomass.

Barbu et al. (2009, 2010) indicate that *Miscanthus x giganteus* can be successfully cultivated on HM contaminated soil as a safe energy crop. Our previous studies conducted on both clean and polluted soils showed that the uptake of metals strongly depended on the level of bioavailable forms. *Miscanthus x giganteus* growing on clean soil may accumulate about 2 mg Pb kg⁻¹, 0.3 mg Cd kg⁻¹ and 25 mg Zn kg⁻¹ while on contaminated soils - up to 200 mg Pb kg⁻¹, 5 mg Cd kg⁻¹ and 700 mg Zn kg⁻¹ (Pogrzeba et al., 2011).

The total metal content in miscanthus biomass was calculated for 1 ha and presented in Fig. 3. The calculated amount of metals in the crop ranged from 2.2 to 4.8 kg ha⁻¹ for Pb, 0.055 to 0.12 kg ha⁻¹ for Cd and 9 to 13 kg ha⁻¹ for Zn (Fig. 3). Differences between particular years were related to the amount of the biomass collected from 1 ha and concentrations of heavy metals in plant tissues.

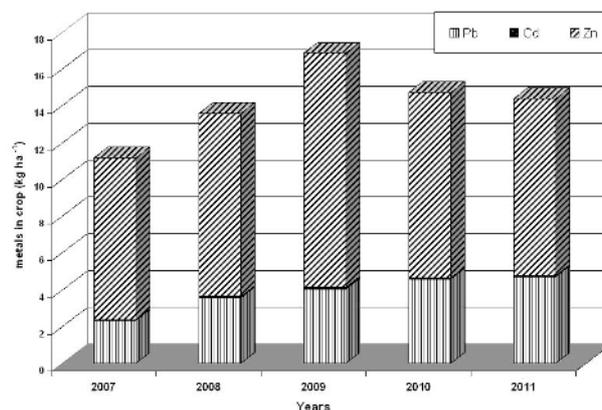


Fig. 3. Metal content in miscanthus biomass calculated for 1 ha.

The presented results showed that cultivation of miscanthus plants on contaminated soil might be associated with elevated levels of heavy metals in their tissues. Contaminated biomass should be treated as a hazardous material. Combustion of such materials should be provided in power plants where the metals oxides could be captured. Moreover, ashes after combustion could contain heavy metals.

During miscanthus development, the leaves senescence and fall down on the ground. This may lead to soil re-contamination. Thus, all the biomass left on the field poses a potential hazard.

Conclusion

Growing miscanthus on polluted soils creates a potential risk of releasing heavy metals into the environment. Thus, the proper soil preparation procedure before planting is a crucial step during miscanthus cultivation. Diminishing of heavy metal migration in soil after application of metal stabilizers should lead to lowering heavy metal content in the biomass.

Combustion of contaminated biomass in household furnaces can cause re-emission of metals to the atmosphere, therefore, that process should be carried out in controlled conditions. Winter harvest of miscanthus causes up to 30% losses of the biomass (leaves fall to the soil surface). Such a phenomenon may lead to re-enrichment of the soil with a metal after the biomass decomposition. The ash after biomass combustion can contain high levels of metals and cannot be used as a fertilizer. Amounts of metals observed in crops suggest that *Miscanthus x giganteus* has a potential for Pb and Zn phytoremediation.

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