THE USE OF BIO-ENERGY CROPS FOR PHYTO-REMETIATION OF METAL ENRICHED SOILS IN THE CAMPINE REGION

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INTRODUCTION

From the end of the 19th century until mid-1970s, zinc and lead were refined at several locations in the north east of Belgium (Campine region; Dutch: de Kempen) using a pyrometallurgical process (Vangronsveld et al. 1995; Hoggervorst et al., 2007). Through atmospheric deposition over the years, an estimated area of at least 280 km² is now enriched with several metals, including Zn, Cd and Pb (OVAM, 2008). Most of these metal enriched soils are in agricultural usage. Because the soils are sandy and acidic there is a great possibility that food and fodder crops might be restricted for safety concern (e.g. potential exceeding of Cd limits). Therefore measures need to be taken. Phytoremediation is a technique that involves the use of plants for the removal of pollutants from the environment or to render them harmless (Garbisu & Alkorta, 2001). It can be considered as a technique that is best suited for the remediation of slightly to moderate and diffusely polluted areas. This type of soil remediation takes place at much lower cost than the conventional methods (Kumar et al., 1995, Rulkens et al., 1998). In the past only plants with natural metal accumulating characteristics such as Brassica sp. and Thlaspi caerulescens were used (Garbisu & Alkorta, 2001, Vassilev et al., 2002). The produced biomass is however low, the metal accumulation is specific and there is a lack of agricultural practices and management (Van Nevel et al., 2007). More recently, also fast-growing crops (maize, barley, oat, ryegrass, triticale, rapeseed) with high biomass production are used for phytoremediation, resulting in a final metal extraction that can be equal to hyper-accumulating plants, despite their lower concentrations in their plant compartments (Vassilev et al. 2002; Meers et al., 2005, Hernández-Allica et al., 2008). In this study, the potential of non-food, and in particular renewable energy crops (e.g. energy maize, rapeseed, short rotation coppice of willow and poplar) for phytoremediation purposes are investigated.
MATERIAL AND METHODS

Site description
All samples were collected from a field (6ha) situated on a moderately contaminated soil in Lommel, Belgium. The planting and management of this site is part of a demonstration project in the context of the INTERREG-project BENEKEMPEN. On this site, 2 ha is reserved for experiments with non-woody biomass. For energy maize 7 different cultivars were sowed in a block design and screened for phytoremediation purposes. Besides energy maize, rapeseed, wheat and triticale are investigated for phytoremediation purposes. The experimental set-up for short rotation coppice (4 ha) consists of a study plot of 2.5 ha for commercialised poplar and willow clones, and a plot for the short rotation coppice breeding program of INBO. The different commercialised clones were planted in a block design of 4 replicates of each 300m². For willow, planting distances of 30 and 60 cm were applied, corresponding with a planting density of respectively 30 000 and 15 000 plants per ha. For poplar, planting distances of 60 and 90 cm are investigated (15 000 and 10 000 plants per ha). The willow clones are Tora, Inger, Loden, and Belgisch Rood and the poplar clones are Muur, Oudenberg, Grimminge, Vesten and Koster. In a separate screening plot the performance of 8 willow clones (Tora, Inger, Loden, Belgisch Rood, Christina, Jorr, Zwarte Driebast and Belders) are investigated. Each clone was planted in 4 replicates in plots of 25 plants with a planting distance of 60 cm.

Sample collection
The sample collection consisted of plant and soil samples. For energy maize 6 representative samples in cross bond over each replicate were taken. The plants were divided in stem, leaves, bract, cob, rachis and corn. From each plant compartment fresh and dry weight were measured, and metal content was determined. The willow samples were taken at each replicate of the screening plot of 8 clones. The poplar samples were collected in the block design of 4 replicates with plant distance of 60 cm. Samples consisted of 4 plants (including leaves). The tree samples were divided in bark, wood and leaf. Fresh and dry weight were measured, the metal content was analysed. Along with each plant sample a soil sample (0-25cm) was taken with an auger (Eijkelkamp p.101).

Sample analysis
Soil samples were oven dried at 50 °C (EU 170, Jouan S.A., Saint Herblain, France) and sieved with a 1mm sieve. pH-H₂O was determined and pseudo-total soil content of heavy metals was estimated by hot plate aqua regia digestion (3:1, v/v, HCl to HNO₃) (Van Ranst et al., 1999). From the different plant compartments the fresh weight was measured, samples were brushed and rinsed with deionised water to remove soil particles and placed in an oven at 60 °C. After measuring, the dry weight samples were grounded using a Culatti DCFH 48 grinder and sieved (Ø 1mm). Plant samples were ashed for 2h at 450°C, dissolved in nitric acid. Metal content was analysed using ICP-OES (Varian Vista MPX, Varian, Palo Alto, CA, USA).
RESULTS AND DISCUSSION

Soil characterisation
The soil Cd concentration at the different sampled plots is very heterogeneous and ranged between 0.5 to 12 mg Cd/kg soil. Other trace metals (e.g. Cu, Pb, Zn) together with the pH and soil conductivity, were more homogeneous distributed throughout the field. As the concentrations of Cd in the sampled plots are exceeding the sanitation norms in Flanders for agricultural land (2 mg/kg), this study will mainly focus on phytoremediation purposes of Cd.

Energy maize
In 2007, the yield of the energy maize amounted to 20 ± 3 ton dry biomass/ha. No great differences in total fresh and dry biomass production could be found between the cultivars. The fresh biomass was mainly situated in the stems and the leaves (57 ± 7 %). The main portion of the dry biomass was situated in the grains (42 ± 5 %). The concentration of Cd in the plant parts was decreasing in following order: stem < leaves < bract < rachis < grain. Because no significant difference in Cd concentration between the cultivars could be measured for each plant compartment, we can conclude that the metal extraction potential is not depending on the used cultivar. The Cd removal rate with energy maize reached a level of 18 ± 3 g/ha. The question of the disposal of the biomass still remains. The Cd concentrations are exceeding limits for fodder crops (1.1 mg Cd/kg dry matter). Therefore the biomass must be used for other industrial purposes such as energy generation. Batch-tests for anaerobic digestion, produced at OWS (Organic Waste systems, Belgium) showed no difference in biogas potential of the silage of the contaminated maize in comparison with a reference material. This offers a good perspective for the use of energy maize as an alternative crop, but further research on metal balance in this process and the disposal of the digestate is still ongoing.

Short rotation coppice
In the willow screening Zwarte Driebast, followed by Loden and Belders, performed best in biomass production. The concentration of Cd in the leaves was higher than the concentration in the bark and the wood. The clones Loden and Tora contained higher concentrations than the other clones. Therefore the clones Loden, Zwarte Driebast and Tora are performing best in Cd removal. Among the poplar clones, Grimminge and Koster are combining a better biomass production with a higher Cd concentration, resulting in a higher Cd extraction potential in comparison with the other poplar clones. Results of short rotation coppice are however provisional, as they are based on measurements of only 2 years of growth instead of a complete rotation cycle of 3 years. Conclusions on phytoremediation purposes can therefore only be obtained after a full rotation cycle and after regrowth measurements following on harvest. The role of clonal selection on extraction potential is obvious. As the leaves represent the highest extraction potential, techniques of harvest of the leaves needs further investigation. After 2 years, the removal of Cd by leaves can be enhanced by 45 ± 3% for willow and 43 ± 8 % for poplar if the removal of the leaves is included.
CONCLUSION

For metal enriched agricultural soils the use of fast-growing crops with a high biomass potential are appropriate for phytoremediation purposes. No significant difference in biomass production and extraction potential is found between different energy maize cultivars. However, consumption for fodder is excluded as the threshold values for Cd are exceeded. Provisional results for usage in energy generation by anaerobic digestion are promising. After 2 years of growth certain willow and poplar clones are showing great potential for phytoremediation purposes, combining elevated biomass production with high Cd concentration. The removal of the leaves could improve phytoextraction rates by 45%. However, final conclusions will only be obtained after a full rotation cycle of 3 years, and after a thorough evaluation of continued growth. Complementary research on environmental risks, metal behaviour and balances during subsequent processing of the biomass and on economical aspects is ongoing. All of this information will allow to fully estimate the feasibility of the various phytoremediation approaches for a safe management of metal enriched agricultural soils.

REFERENCES


