Energy maize for phytoremediation of metal-enriched soils and production of energy: The Campine region, Belgium

V. Van Slycken, N. Witters, E. Meers, K. Adriaensen, T. Thewys,
J. Vangronsveld, F.M.G. Tack
Laboratory of Analytical Chemistry and Applied Ecochemistry,
Ghent University, Coupure Links 653, 9000 Gent, Belgium
Contact: stijn.vanslycken@ugent.be

Introduction

Atmospheric deposition of trace metals (e.g., Cd, Zn and Pb) from metal refinery activities over the last century has caused elevated concentrations in agricultural soils in the Campine region. Regional policy therefore prescribes that the soils should be remediated, while at the same time it is desirable to keep the income of the farmers constant. Both goals can be achieved using phytoremediation in combination with the growth of energy crops and brings us to the concept of a multi-functional biomass system (Berndes *et al.*, 2008). Phytoremediation involves the use of plants for the removal of pollutants from the environment or to render them harmless (Garbisu & Alkorta, 2001).

Methods

For the study of phytoremediation potentials with energy maize 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.

The concentrations of Cd in this study area vary between 0.5 and 12 mg Cd kg^{-1} soil. Other trace metals (e.g., Cu, Pb and Zn) together with the pH and soil conductivity were more homogeneously distributed throughout the field. As the concentrations of Cd in the sampled plots are exceeding the threshold values for remediation for agricultural land (2 mg kg^{-1}) in Flanders, this study will mainly focus on phytoremedation purposes of Cd. In this field 1 ha was reserved for investigations with energy maize. Regional policy prescribes that the soils should be remediated, while at the same time it is desirable to keep the income of the farmers at a constant level. Therefore, the impact on the revenue of the farmer originating from the phytoremediation activities is calculated. To take into account the uncertainty involved, sensitivity analyses are performed for several variables. The final aspect included is the energy component of the project: an input-output ratio is calculated and avoided CO_2 emissions are given.

Results and discussion

In the site for screening of energy maize, the total concentration measured in an *aqua regia* destruction is 5 ± 1 mg Cd kg^{-1} soil. In 2007, a yield of 20 ± 3 ton dry biomass/ha was obtained. No significant difference in Cd concentration between the cultivars could be measured for each plant compartment (stem, leaves, bract, rachis, grain). Also no great significant difference was found in yearly removal of trace element between different the investigated cultivars, so that the yearly removal of Cd can be estimated at 18 ± 6 g Cd ha^{-1}. For total removal of 5 mg Cd kg^{-1} soil to 1.2 mg Cd kg^{-1} soil (acceptable value) more than 800 years will be needed when energy maize is used.

Nevertheless, the Cd concentration in the biomass is exceeding legal threshold values for fodder crops (1.1 mg Cd kg^{-1} dry matter) which implies that the biomass produced cannot be used as fodder but must be applied for other industrial purposes such as energy generation. Batch-tests for anaerobic digestion, performed 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 points out that energy maize does not have as its main goal remediation of the contaminated soil, but as a more valuable alternative for the farmers. Energy maize as an alternative crop offers great potential, but further research on metal balance in this process and the disposal of the digestate is still ongoing.

Economic measurements need to be included to fully evaluate phytoremediation purposes. We start from the assumption that basic activities remain (dairy cattle rearing). Therefore, energy maize is grown and fodder maize has to be bought outside the contaminated area. When the biomass from energy maize is used for energy production by digestion, the basic income of the farmer can be supported by using and selling renewable energy (heat and electricity) out of this polluted biomass. When farmers digest the maize themselves and former activities and revenues thereof remain, their average yearly net income will grow with € 227 ha^{-1}, to be added to the basic income of € 1.047 ha^{-1} (2005). However, Risks, legal norms and extra efforts needed in such a project cannot be underestimated. A farmer can therefore decide to sell the polluted energy maize by contracts with an energy partner that converts the polluted biomass into energy. In the latter case, the average yearly income of the farmer grows with € 115 ha^{-1}.

As already mentioned, the project is conceived as a multi-functional biomass system. Another environmental benefit, besides remediation, of this project is the production of 'green' energy. Taking into account all energy input (going from transport of fodder to processing the waste product), digestion of energy maize delivers for each part of fossil energy input, 8–12 parts of renewable energy. One hectare of energy maize delivers a net yield of 80 GJ electricity and 30 GJ heat, to be sold locally or to be used on the farm. In a traditional installation (coal), this amount of electricity would cause an emission of 9.6 t CO_2.

To study the possibilities for phytoremediation of trace elements in the Campine region, using energy crops, an integrated study is needed. The agronomical study of energy maize shows that the produced biomass is comparable with energy maize grown on non-contaminated sites. Because of the low concentration of trace elements in the different plant parts, a long remediation period is needed. Nevertheless, the high biomass and low concentration are very promising for its use in the non-food industry, including the provisional results for usage in energy generation by anaerobic digestion. Moreover, the economic outlook for the farmers in the contaminated region is positive, as simulations have shown. In this paper, energy maize is, therefore, presented as a sustainable alternative for traditional farming activities. Research is also ongoing for other crops like short rotation coppice and rapeseed. These crops can show even higher extraction rates, but have disadvantages concerning economic, energetic or social aspects. All this information combined with metal balances in the different energy flows will allow full comprehension of the feasibility of the various phytoremediation approaches for a safe management of metal enriched agricultural soils.

References

Berndes, G., *et al.*, 2008. Biofuels, Bioprod. Bioref. 2: 16-25.
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