Comparison of chemically-enhanced phytoextraction by arable crops and short rotation coppice with hyperaccumulator plants

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INTRODUCTION

Phytoextraction is often suggested as a low cost, *in situ* tool for soil remediation that offers several advantages over more conventional techniques (Cheney *et al*., 1997). However, despite substantial research in recent years, phytoextraction has not become a widespread commercial reality. Three main techniques have emerged: the use of hyperaccumulator plants, chemically-enhanced uptake of metals by high biomass arable crops, and the use of short rotation coppice species (McGrath *et al*., 2001). Although much research has focused on the genetic modification of crops, it has been suggested that some important issues have been overlooked, including plant performance under field conditions (Baker and Whiting, 2002). The present study aimed to compare the efficacy of the three main phytoextraction techniques for the remediation of soils historically contaminated with processed sewage sludge using field experiments.

MATERIALS AND METHODS

Field trials were established at a sewage sludge disposal facility in England in April 2000. A 12 x 140 m plot of *Zea mays* was established and chemical interventions were applied during flowering to sub-plots arranged in a randomised block design. These included differing rates of: i) EDTA, to increase soil metal solubility; ii) KCl, to increase plant Cd uptake following chloro-complexation; and iii) glyphosate, a potential inducing agent for metals. The *Z. mays* crop was harvested in August 2000. Three 2 x 2 m plots of the Ganges and Prayon populations of the hyperaccumulator species, *Thlaspi caerulescens*, were established in May 2000 using pre-germinated seedlings and harvested in July 2000. A 12 x 85 m plantation containing two *Salix* species (Loden and Calodendron) was also established. Chemical interventions, including differing EDTA and HCl treatments, were applied to randomised sub-plots from April 2001. The plants were harvested in August 2001. Standard soil and plant analysis procedures included measurements of total metal concentrations by flame-AAS.

RESULTS AND DISCUSSION

The mean total soil Cd and Zn concentrations within the experimental plots were 44 ± 5.4 and 2300 ± 88 mg kg^{-1} respectively. Available soil phosphate was 256 ± 23 mg kg^{-1}, approximately ten times the concentration for typical UK agricultural soil; soil pH was 6.1. A summary of the maximum plant Cd and Zn uptake is shown in Table 1. Some significant increases ($P < 0.01$) in plant Cd and Zn concentrations were observed following chemical interventions, for example, Cd and Zn uptake by *Z. mays* following application of EDTA at 2 or 10 mmol kg^{-1}. However, the overall metal uptake by *Z. mays* was relatively low. Cd uptake was greatest for the Ganges population of *T. caerulescens* and although this plant is capable of accumulating Cd to extremely large concentrations (Lombi *et al*., 2000), limited solubility of soil Cd in the present study restricted uptake to far below its potential maximum. The overall Zn yield was greater for *S. dasyclados* than in either population of the hyperaccumulator, *T. caerulescens.* The timescale and cost of phytoextracting the test soil to bring metal contents within current legislative metal thresholds was calculated. Assuming a constant soil → plant transfer factor, a period exceeding 500 years would be required to reduce total soil Cd below 3 mg kg^{-1} using the Ganges population of *T. caerulescens*. To reduce total soil Zn to below 300 mg kg^{-1}, a period exceeding 1000 years would be required for all plant types examined. Phytoextraction costs were estimated to be large and are probably in excess of those for other remediation techniques.

Table 1. Cd and Zn concentrations and yields for a number of different phytoextraction crops grown on soil historically contaminated with sewage sludge. Figures are for maximum plant uptake. Chemical intervention details are indicated where applicable.

Crop	Above-ground biomass (t ha^{-1})	Cd Concentration in Shoots (mg kg^{-1})	Cd Removal (kg ha^{-1} y^{-1})	Zn Concentration in Shoots (mg kg^{-1})	Zn Removal (kg ha^{-1} y^{-1})
T. caerulescens (Ganges)	2.51	265	0.66	1009	2.53
T. caerulescens (Prayon)	3.03	20.5	0.06	844	2.55
S. caprea x cimeria x viminalis (Calodendron)	13.07	9.41**a**	0.12	169**a**	2.21
S. dasyclados (Loden)	31.53	10.72**b**	0.33	198**b**	6.09
Z. mays	12.50	7.62**c**	0.09	117**d**	1.46

a Weighted concentration in leaf and stem fraction following application of 10 mmol kg^{-1} HCl solution.
b Weighted concentration in leaf and stem fraction.
c Uptake following application of 10 mmol kg^{-1} EDTA solution.
d Uptake following application of 2 mmol kg^{-1}EDTA solution.

CONCLUSIONS

Several plant species were examined under realistic phytoextraction regimes in field experiments. Although a variety of chemical inputs were examined and some significant increases in plant Cd and Zn uptake were observed, overall metal uptake was generally low. Estimated remediation times and associated costs were prohibitive even for hyperaccumulator plants. The identification of improved techniques for increasing the solubility of soil metals will be important for successful phytoextraction of sites historically contaminated with sewage sludge.

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