Phytoextraction of Cd and Zn by the hyperaccumulator plant Thlaspi caerulescens as affected by plant size and origin

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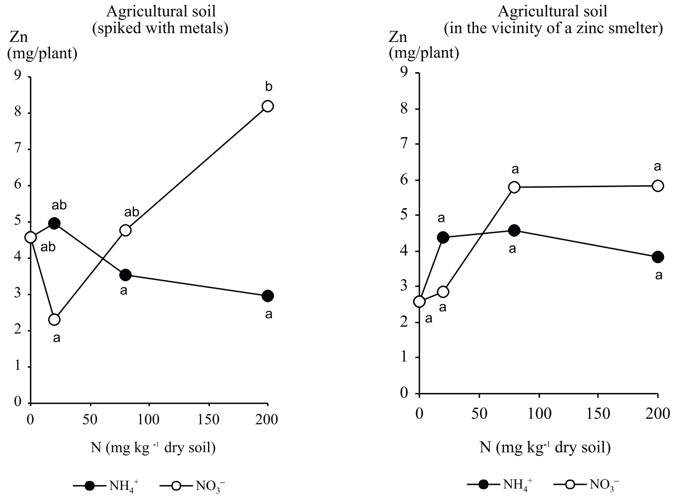

Fig. 3. Extraction of zinc by *Thlaspi caerulescens* with increasing rates of nitrogen soil amendment.

80 mg N kg^{-1}, i.e. 240 kg N ha^{-1} in two 120 kg ha^{-1} applications.

Field experiment

Biomass production. Both populations showed very similar biomass productivity with mean values of 3.17 g DM per plant for population A and 3.46 g DM per plant for population B. No symptoms of metal phytotoxicity were recorded. Results showed that plant growth was significantly higher on sludge-amended soils at a rate of 15 t ha^{-1} than on controls.[3] The number of hyperaccumulator plants harvested was 1007 for population A and 1114 for population B. The regrouping of plants by dry weight classes showed an increase in the heaviest plants (classes C2 and C3) when the rate of added sludge increased.

Metal uptake. Addition of urban sludge increased both plant biomass production and extraction of metals by the two plant populations. The Zn concentration increased twofold from the control plots to rate B2 (15 t DM sludge per ha). (Fig. 4). The Cd concentrations were not significantly modified in population A but strongly increased in population B (Fig. 5). This concentration was 2.4 times higher in the sludge-amended plots than in controls. There was a slight decrease in Zn concentrations in the largest hyperaccumulator plants. Nevertheless, the decrease was only significant for population A between classes C1 and C3. For population B the Zn concentrations were remarkably constant throughout the dry weight classes except for the plots where no sludge was added. In each dry weight class the Zn concentrations increased with sludge addition. This difference is only statistically significant (Newman-Keuls test, $P < 0.05$) for class C3 (~5 g DM) of population B. With addition of sludge, the Zn concentrations in the plants belonging to the same weight class were systematically higher for population B. This difference was statistically significant for the plants from class C3. The Cd concentrations in the shoots of population B as affected by the dry weight classes followed the same trend as the Zn concentrations. The concentrations of Cd in the shoots of population B were very clearly higher than in population A, where they were negligible. Population B responded strongly to the addition of sludge for Cd as for Zn.

Quantities of metals extracted by shoots of T. caerulescens: *effect of size and origin.* The extraction of Cd and Zn is given as mass of metal per plant. In spite of higher biomass production, population A extracted less Zn than did population B (Fig. 6). This difference in metal extraction is significant only for the largest plants (C3). For population B, the increased biomass productivity seemed to increase Zn extraction. The Cd extraction was quite spectacular because of the high concentrations of Cd in the shoots (Fig. 7). Population B extracted 30 times more Cd than did population A when sludge was added to the soil. The largest plants contributed mainly to the Zn and Cd extraction from the soil. Extraction of metals was enhanced by increase in biomass despite a slight reduction in the metal concentration in plant tissues of larger plants. Again, this reduction was lower than that deduced from the dilution effect of increased biomass. The plants from the population collected in site B showed very high Cd concentrations in the leaves compared to the population from site A.

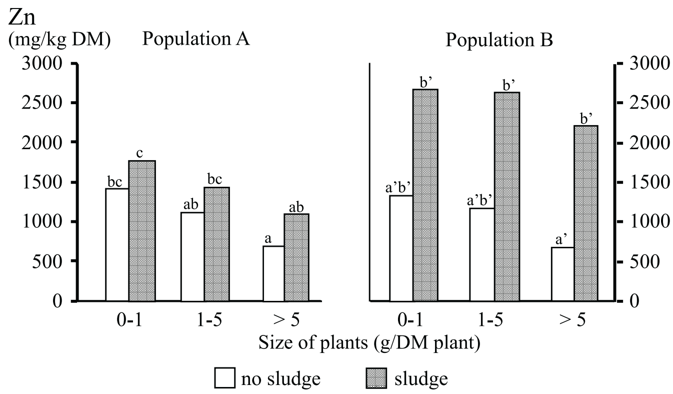

Fig. 4. Zinc content in shoots of *Thlaspi caerulescens* according to size and origin of plants; a, b, c: homogeneous groups determined by the Newman-Keuls test ($P < 0.05$) for each population.

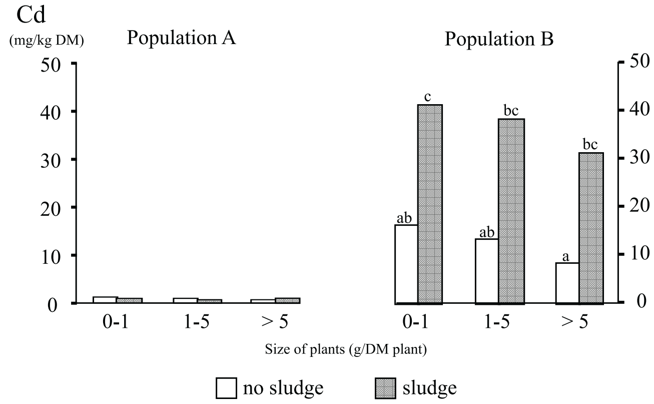

Fig. 5. Cadmium content in shoots of *Thlaspi caerulescens* according to size and origin of plants; a, b, c: homogeneous groups determined by the Newman-Keuls test ($P < 0.05$) for each population.

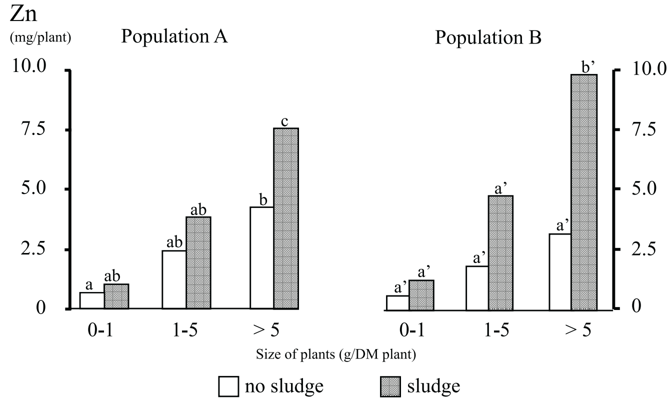

Fig. 6. Zinc extraction by shoots of *Thlaspi caerulescens* in mass of metal per plant according to their size and origin; a, b, c: homogeneous groups determined by the Newman-Keuls test ($P < 0.05$) for each population.

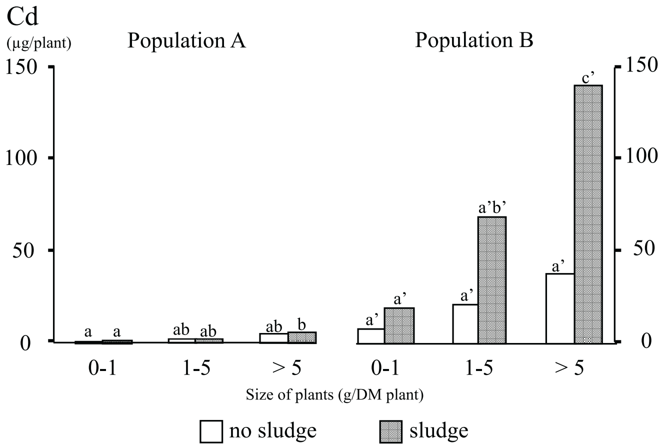

Fig. 7. Cadmium extraction by shoots of *Thlaspi caerulescens* in mass of metal per plant according to size and origin; a, b, c: homogeneous groups determined by the Newman-Keuls test ($P < 0.05$) for each population.

Discussion

The selection of the most effective population of hyperaccumulator plants and, within this population, of the most effective individuals can strongly enhance phytoextraction. Field experiments demonstrated the positive effect of sludges on the yield of wild hyperaccumulator plants. This outcome is greater after two years of sludge application. The metal concentrations in the sludges applied in our experiment were high and added metals to the soil from 23 mg Zn kg^{-1} and 0.24 mg Cd kg^{-1}. The concentrations of metals were, however, below French standards for sludge application. The Cd and Zn contents in the leaves of *T. caerulescens* increased considerably as a result of the addition of sludge. Generally, for most plant species, an increase in biomass production induced a decrease of the metal concentrations in the tissues. For the two *T. caerulescens* populations, this effect of dilution was very moderate because of the high internal requirement for Zn. The concentration of Zn in shoots of *T. caerulescens* was lower in the presence of ammonium. This could be a result of an interaction between NH_4^+ and Zn^{2+} for absorption, as both cations are present in plant tissues at similar concentration. The same conclusion was reached for the Cd concentrations, which were only slightly affected by the increase in biomass. As a result, the extraction of Cd and Zn was raised significantly with increase in dry matter yield. Furthermore, the production of biomass by the aerial parts of *T. caerulescens* was strongly increased by appropriate fertilization, especially that of nitrogen.

The genus *Thlaspi* includes several species of Zn hyperaccumulator with different abilities of accumulation. In the case of *T. caerulescens,* these differences were observable between populations. Population B showed a remarkable ability to extract Cd from the soil compared to population A which accumulated only very low Cd contents in the tissues. Furthermore, the Zn contents in the above-ground parts of population A were slightly lower than in population B. The similarity of the fate of both metals, Cd and Zn, in the soil-plant system was evident. Consequently, population B offers a higher potential for phytoextraction. In one population, the response of the plants varied widely for biomass production as well as for metal contents. This variability could present an advantage in selecting the most effective individuals.

Conclusion

Efficiency of phytoextraction is related to the ability of the plant to grow on polluted soils and produce a large biomass with a high concentration of metal in the above-ground parts. Shoot dry matter production and heavy metal content of leaf tissue of the hyperaccumulator *T. caerulescens* from two different populations differed according to the size of the plants. The results are very promising and indicated the plants' ability to lower soil Cd and Zn concentrations. The largest individual plants, especially in population B, contributed most to the extraction of Cd and Zn from the soil. Our methods may easily be adapted to selecting other hyperaccumulating plants for the remediation of contaminated sites. In seeking to develop phytoextraction methods, it is better to give greater prominence to hyperaccumulators than to high-biomass plants in which the extracted metals are diluted. Successful transfer of phytoextraction methods from the laboratory to the field is a crucial step in the practical development of this technology. Furthermore, adding fertilizers with sludge, which increases biomass production of hyperaccumulating plants can be extremely effective in improving phytoextraction in the laboratory and in the field and can make this process more cost effective.

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