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The potential of *Thlaspi caerulescens* for phytoremediation of contaminated soils

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Abstract

Uptake of Cd, Zn, Pb and Mn by the hyperaccumulator *Thlaspi caerulescens* was studied by pot trials in plant growth units and in populations of wild plants growing over Pb/Zn base-metal mine wastes at Les Malines in the south of France. The pot trials utilised metal-contaminated soils from Auby in the Lille area. Zinc and Cd concentrations in wild plants averaged 1.16% and 0.16% (dry weight) respectively. The unfertilised biomass of the plants was 2.6 t/ha. A single fertilised crop with the above metal content could remove 60 kg of Zn and 8.4 kg Cd per hectare. Experiments with pot-grown and wild plants showed that metal concentrations (dry weight basis) were up to 1% Zn (4% Zn in the soil) and just over 0.1% Cd (0.02% Cd in the soil). The metal content of the plants was correlated strongly with the plant-available fraction in the soils as measured by extraction with ammonium acetate and was inversely correlated with pH. Bioaccumulation coefficients (plant/soil metal concentration quotients) were in general higher for Cd than for Zn except at low metal concentrations in the soil. There was a tendency for these coefficients to increase with decreasing metal concentrations in the soil. It is proposed that phytoremediation using *Thlaspi caerulescens* would be entirely feasible for low levels of Cd where only a single crop would be needed to halve a Cd content of 10 μg/g in the soil. It will never be possible to remediate elevated Zn concentrations within an economic time frame (<10 yr) because of the lower bioaccumulation coefficient for this element coupled with the much higher Zn content of the soils.

Introduction

The inordinately high uptake of Zn by *Thlaspi calaminare* (Lej.) Lej. and Court. (Brassicaceae) was first described by Baumann (1885) who found that this plant accumulated over 1% Zn in dry tissue. This represents the first record of a plant *hyperaccumulator* of a heavy metal. The term hyperaccumulator was first used by Brooks et al. (1977) in relation to plants containing more than 1000 μg/g (0.1%) Ni in dry tissue. Later, Reeves and Brooks (1983) studied uptake of Zn by numerous *Thlaspi* L. species and found several that were able to hyperaccumulate both Zn and Ni. The threshold of hyperaccumulation for Zn was set at 10,000 μg/g (1%) in dry matter.

It was not until the early 1980s (Chaney, 1983) that it was realised that hyperaccumulators might be used to remediate polluted soils by growing a crop of one of these plants and harvesting it to remove the pollutants. A benchmark paper by McGrath et al. (1993) reported the results of field trials in which several hyperaccumulators were grown in polluted soils to reduce the soil content of Zn from 440 μg/g to <300 μg/g (the threshold established by the Commission of the European Community (CEC, 1986).

During the past five years there has been increasing interest in the possibility of using plants to remediate

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contaminated soils (Salt et al. 1995) because of the high cost and environmentally undesirable alternatives such as:

1. removal and storage of such soils;
2. covering soils with concrete or fresh topsoil;
3. acid leaching of heavy metal pollutants from soils.

The most important consideration in phytoremediation is that the plant should translocate metals from the soil to the aerial parts allowing a significant quantity of metal to be removed from the soil with each crop. There are hyperaccumulators of several heavy metals including As, Cd, Cu, Co, Mn, Ni, Pb and Zn (Brooks et al. 1995) which could potentially be used for phytoremediation. In some cases, there are plants (such as *Thlaspi* L.) that can hyperaccumulate two or more elements at the same time and there is also the possibility of growing a mixed crop of two or more species to improve the versatility of the phytoremediation method.

Suitable plants for phytoremediation operations generally fall into two categories. The first is plants such as *Thlaspi* with a very high foliar metal concentration, that usually do not provide a high annual biomass. The second category consists of plants such as *Brassica juncea* (Indian mustard) that have a lower metal concentration but have a large biomass production so that the actual amount of removed metal is higher.

Thlaspi caerulescens J.C. & R. Presl falls into the first category. It is a biennial herbaceous plant which is known to have a very high foliar Zn content (up to 3% dry weight – Baker and Brooks, 1989). It will also hyperaccumulate Cd and Ni (>0.1% d.w. in each case). It occurs frequently on mineralised soils, particularly those with a high Zn content.

Except for studies by McGrath et al. (1993) and Brown et al. (1994, 1995a), most experiments with *Thlaspi caerulescens* (Brown et al., 1995b; Pollard and Baker, 1996; Vázquez et al., 1992) have used hydroponic experiments to test the behaviour of this species with respect to Zn and Cd. Hydroponic experiments are perhaps favoured probably because it is very easy to control the conditions so that the data are inherently more reproducible than where soil mixtures are used. We believe however, that experiments such as ours, using soils rather than solutions, approximate more closely to field and natural conditions where the effect of soil buffering capacity influences nutrient availability to plants.

The aims of this present study were to investigate the phytoextractive potential of *T. caerulescens* to remediate metal-contaminated soils and involved a combination of both pot trials and studies on wild plants. Specific aims were to:

1. determine what metals might be extracted using *T. caerulescens*;
2. establish how much metal could be extracted per hectare per annum;
3. calculate the number of annual crops that might be needed to decontaminate soils with specific metal concentrations;
4. relate bioaccumulation coefficients (plant/soil metal concentration quotients) to the total metal concentration in the soil.

Materials and methods

Site description

Samples were collected from sites around St Laurent le Minier, Southern France (Figure 1). The region, known as Les Malines, is the location of one of the largest base metal mines in Europe that has been exploited since Roman times and only ceased operations about 5 yr ago. The mineralisation consists of Zn/Pb sulphides and oxides associated with barite. Although operations have now ceased, an attempt is being made to revegetate and ameliorate the enormous area of mine waste that now surrounds the little town of St Laurent le Minier.

The mine tips contain typically several percent of both Pb and Zn with associated thallium and Cd.

The pH of the tailings is typically 7.3 (mean of 60 samples) with a range of 6.4–7.7. The surprisingly high pH is due to the presence of calcareous material in the tailings. The mine waste has been colonised by a typical base metal flora dominated by *Minuartia verna* (L.) Hiern. and *Thlaspi caerulescens* with associated *Iberis intermedia* Guersent and *Armeria maritima* (Miller) Willd. Figure 2 shows a view of the base-metal plant community in this region.

Sample collection

Sixty plants were taken at various sites within Les Malines. The soils in which the plants were growing were also sampled. The diameter of each plant was measured and the dried (70 °C) plant weighed. From these values an estimation of the biomass production per hectare could be made. This was done by calculating how many plants could cover one hectare assuming

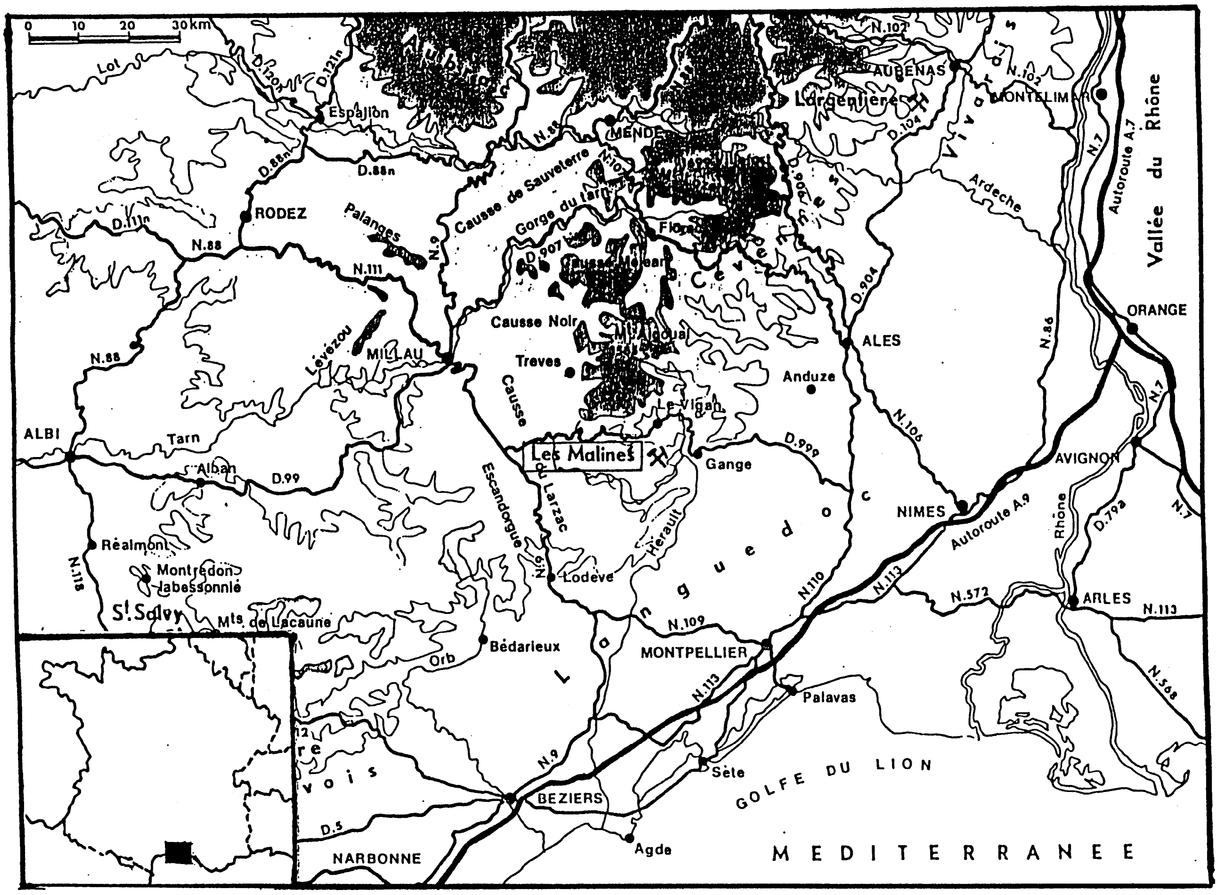

Figure 1. Location map of the Les Malines base metal mining area of southern France. Dark areas are land over 1000 m altitude.

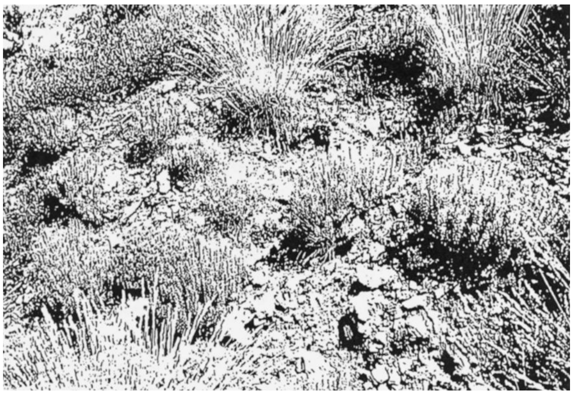

Figure 2. View of the metal-tolerant plant communities (mainly *Thlaspi caerulescens*) over the base-metal mine waste of the Les Malines mining area near St Laurent le Minier, France.

70% ground cover. This value was then multiplied by the dry weight of the plant to give the theoretical yield per hectare.

Experiments performed in plant growth units

Contaminated soil from the town of Auby, Northern France was used in the glasshouse experiment. The Auby soil contained 4% Zn, 1% Pb and 360 μg/g Cd and was mixed with soil from the University of Lille (which contains negligible amounts of these elements) in the following proportions (Auby:Lille): 1:0, 1:1, 1:3, 1:7, 1:15, 0:1.

Whereas the soil used in the glasshouse experiment was different to that sampled in the field survey, both were heavily contaminated by similar sources, i.e. smelting/mining operations. An experimental protocol was developed that avoided the use of addition of soluble metal salts to soil in order to study metal rate/plant response functions, a practice known to poorly simulate the behaviour of metal contaminants *in situ*. The highly contaminated Auby soil (pH 7.0) was mixed with a non-contaminated soil (of similar pH and mineralogy) from the University of Lille at Villeneuve d'Ascq.

A few seeds of *Thlaspi caerulescens* (from Les Malines near Montpellier) were placed in individual 250 mL pots (10 containers for each of six mixtures). After germination and appearance of the first pair of true leaves, seedlings were thinned out to leave only one in each pot. The growth medium had a bulk density close to 1.0. There were no added nutrients but the plants were watered as required and the pots rotated in a random manner to equalise light exposure. The experiments were performed in an unheated plant growth unit and the growing period was May–November 1996. The plants were harvested and analysed as described below.

Preliminary sample treatment

Plants were rinsed thoroughly in distilled water and dried at 50 °C. Approximately 0.2 g of material from each plant was accurately weighed into a set of 20 mL boiling tubes. Concentrated nitric acid (10 mL) was added to each tube and the mixtures heated on a heating block until a final volume of ca. 3 mL was reached. The samples were then diluted to 50 mL using distilled water and stored in polythene containers.

Soil digestion

Soil samples were dried at 50 °C and sieved to <2 mm size using a nylon sieve. About 0.2 g quantities of sieved soil were ground using a mortar and pestle and then accurately weighed into boiling tubes. Ten mL of concentrated nitric acid was then added and the mixtures boiled until a final volume of 3 mL was reached. A further 10 mL of concentrated hydrochloric acid was then added and the mixtures again evaporated to 3 mL. After filtration, the solutions were diluted to 100 mL with distilled water.

Estimation of the pH and plant-available elemental fractions in the soils and mine waste

Approximately 5 g samples of sieved soil were weighed accurately into 150 mL polythene containers. Then 50 mL of 1M ammonium acetate was added to each container. Samples were gently agitated (75 rpm) for 24 h, filtered (Whatman No. 41), and stored in polythene containers. Ammonium acetate was chosen for the experiments because of its well proven use as a measure of the plant-available fraction of soils (Ernst, 1996).

The pH measurements were made by shaking 4 g samples of soils or mine waste with 10 mL of distilled water for a period of 1 h. After being allowed to settle for 24 h, the samples were again shaken for a few minutes and the pH measured after an appropriate settling period.

Chemical analysis

Chemical analyses on the plant and soil solutions were performed using a GBC 904 atomic absorption spectrometer. The following elements were quantified: Cd, Mn, Pb and Zn.

Results and discussion

Accumulation of metals by wild specimens of Thlaspi caerulescens

The metal content of wild plants and associated soils collected from St Laurent le Minier is shown in Table 1. Since the data were lognormally distributed, the data (all as % except where otherwise stated) are shown as geometric means with the corresponding standard deviation ranges.

All plant specimens contained elevated concentrations of Cd, Mn, Pb and Zn relative to 'normal' plants growing in non-mineralised soils (see Table 1), for which respective concentrations of these four elements are of the order of 0.5, 10, 5 and 20 μg/g in the dry plant material (Brooks et al., 1995). From Table 1 it will be noted that the mean elemental contents of Cd, Mn, Pb and Zn in one-year-old plants were respectively 3236, 6.1, 169 and 581 times higher than for other plants growing in non-mineralised soils. For two-year-old plants the respective values were 1054, 1.6, 44 and 262. The lower metal concentrations in older plants may be due to the dilution effect of higher biomass if metal uptake is not proportional to this biomass increase. It might have been argued that the higher metal concentrations in younger plants could be due to their greater proximity to the ground and hence greater risk of contamination from wind-borne soil. However, if all the Pb content of the plants is assumed to be due to contamination, and knowing the Cd/Pb and Zn/Pb quotients in the soils (0.01 and 2.30, respectively) corrected concentration values can be obtained for Cd and Zn in *Thlaspi* that do not differ greatly from the total metal burden (see Table 1). Because the Cd concentration in the plants was considerably higher than that in the soil, the effect of contamination from wind-blown dust would have been to reduce the orig-

Table 1. Mean (geometric) elemental concentrations (μg/g in dry matter) in wild populations of *Thlaspi caerulescens* growing over base-metal mine wastes at St Laurent le Minier, near Montpellier, southern France. Values in parentheses are the standard deviation range

Material	N	Zn	Cd	Pb	Mn
Soil (geom. mean)	60	38,010	163	16,531	688
(std. dev. range)	60	9907–157,939	45–997	3074–67,427	144–4493
Normal[a] plants	–	20	0.5	5	10
One-year *Thlaspi* plants (geom. mean)	40	11,627	1618	844	61
(std. dev. range)	40	5463–27,385	378–3689	95–4318	10–515
(corrected values[b])	40	10,207	1695	–	59
Two-year *Thlaspi* plants (geom. mean)	20	5242	527	219	16
(std. dev. range)	20	1137–29,238	107–2413	6–2143	3–152
(corrected values[b])	20	4866	532	–	7

[a] Mean elemental concentrations to be expected in vegetation not growing over mineralisation (Brooks et al. 1995).
[b] Corrected values assuming that all of the lead content is derived from wind-borne contamination.

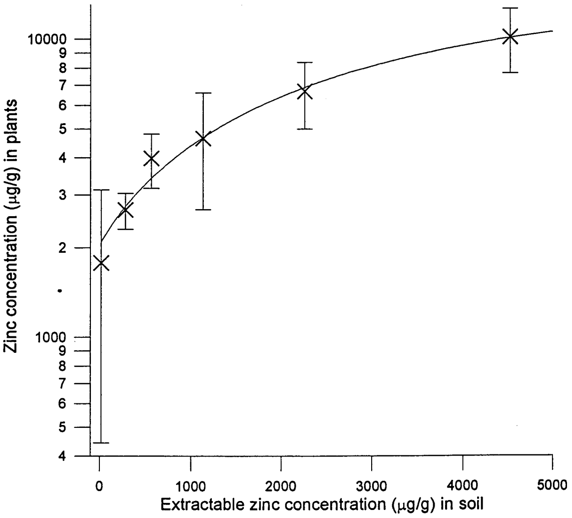

Figure 3. The zinc content of specimens of *Thlaspi caerulescens* as a function of the extractable zinc content of the soil.

inal metal content of the plants rather than to increase it.

Table 1 also shows the ‘corrected’ Cd and Zn concentrations in the plants, assuming that the entire Pb burden is derived from wind-blown contamination.

Metal accumulation by T. caerulescens *under controlled conditions*

The results of experiments with *T. caerulescens* raised in plant growth units at the University of Lille are shown in Figures 3 and 4. In the case of Zn (Figure 3) there was a gradual increase of the metal concentration in the plants to about 1% d.w. as the extractable Zn concentration in the soil increased to 0.5%. A similar observation can be made for Cd (Figure 4) where there appeared to be a limiting value approached 0.2% (2000 μg/g) for soils containing 50–70 μg/g extractable Cd. There was no detectable decrease in biomass yield for increasing metal concentrations in the soil except at the very highest concentrations of 0.5% Zn and 50 μg/g Cd.

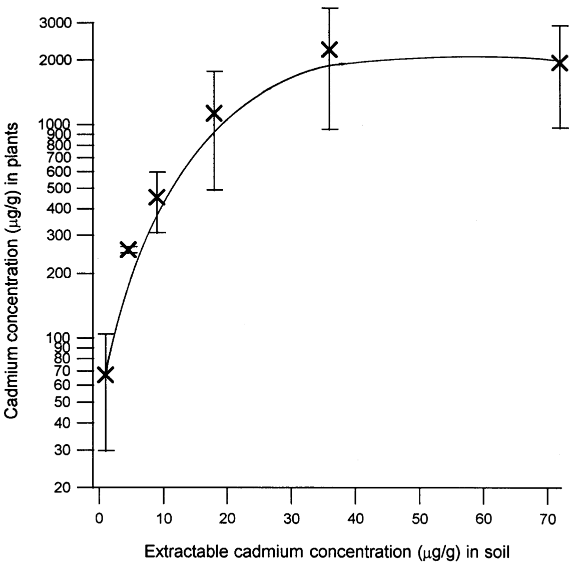

Figure 4. The cadmium content of specimens of *Thlaspi caerulescens* as a function of the extractable cadmium content of the soils.

Bioaccumulation coefficients (concentration of the metal in dried plants divided by the extractable soil content of the same element) for Zn and Cd as a function of the total metal content of the soil for the plant growth unit experiments are shown in Figures 5 and 6.

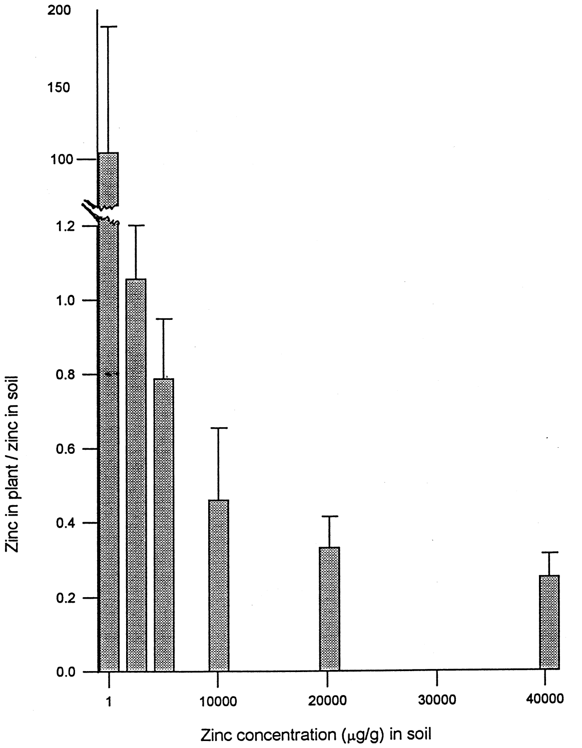

Figure 5. Bioaccumulation coefficients (plant/soil concentration quotients) for zinc in *Thlaspi caerulescens* as a function of the total zinc content of the soils.

Inspection of these two plots allows for the following observations to be made:

1. In the case of Zn (Figure 5), bioaccumulation coefficients (BC) decreased with increasing metal content in the soil. The BC values ranged from 104 (0.0017% Zn) to 0.25 (4% Zn). For Cd (Figure 6) the BC values ranged from 67 (1 μg/g Cd) to 5.4 (360 μg/g Cd). It follows therefore, that if *Thlaspi caerulescens* were to be used for phytoremediation of Cd and Zn in contaminated soils, the efficiency of removal would be inversely related to the degree of contamination of the substrate, since BC values are higher at these lower concentrations of the two metals.

2. As indicated by the high error bars (i.e. standard deviations) of the data points in the two figures, there was a great deal of variability in individual metal contents. For example, the Cd content of the plants varied from 1000–4000 μg/g for 200 μg/g Cd in the soil. In the case of Zn, the corresponding figures were 2500–7500 μg/g for 1% of this metal in the soils. This large variation between individuals was encountered despite the plants being closely controlled and having been planted in homogeneous soil mixtures.

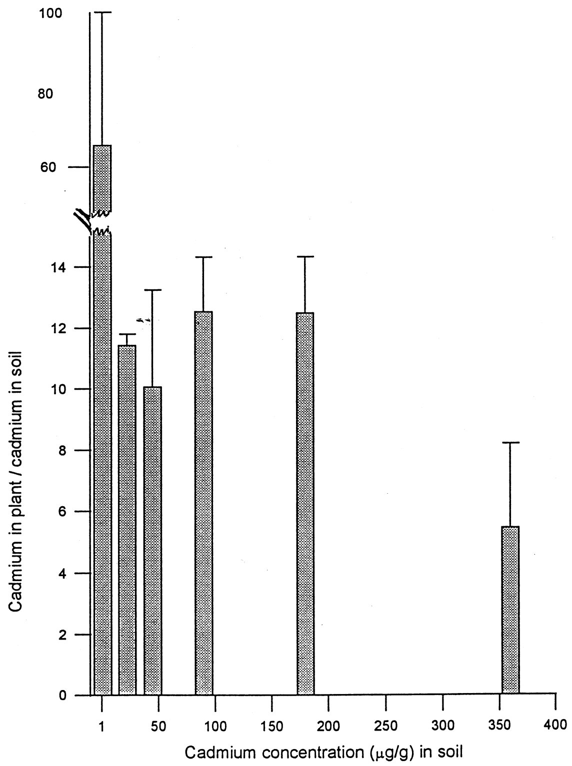

Figure 6. Bioaccumulation coefficients (plant/soil concentration quotients) for cadmium in *Thlaspi caerulescens* as a function of the total cadmium content of the soils.

The high degree of variability of metal levels in *T. caerulescens* found in our study has been mirrored in hydroponic experiments by Pollard and Baker (1996) who reported 1.8–3.3% Zn in foliar material. McGrath et al. (1993) reported a range of Zn concentrations from 0.25–0.66% in plants for a metal content of just under 300 μg/g in the soil.

Biomass production of Thlaspi caerulescens *under natural conditions*

Our field observations and measurements on natural populations of *Thlaspi caerulescens* growing over base-metal waste near St Laurent le Minier, southern France, have shown that unfertilised plants have an annual biomass production of 2.6 t/ha. This is very low compared with maize (30 t/ha) or even the Ni hyperaccumulator *Alyssum bertolonii* at 4.5 t/ha (Robinson et al., 1997). Taking the mean Zn content of the plants of 1.16% (Table 1) and Cd content of 0.16%, it can be calculated that a crop of this same biomass could remove 30.2 kg/ha of Zn and 4.2 kg/ha of Cd.

Bennett et al. (1998) have shown that fertilising crops of *T. caerulescens* grown in base-metal mine tailings from the Tui Mine, Te Aroha, New Zealand, can increase the biomass by a factor of three without appreciable reduction in the Zn or Cd concentrations. If we adopt a conservative approach and use a factor of two, a biomass production of 5.2 t/ha would yield 60 kg/ha of Zn and 8.4 kg/ha of Cd. This is in reasonable agreement with the findings of McGrath et al. (1993) who reported 30.1 kg/ha for Zn extracted by moderately fertilised plants from soils containing only 444 μg/g. In relative terms, the data of McGrath et al. (1993) indicate a much higher uptake than found by us. However, as mentioned above, BCs are much higher for lower metal concentrations in the substrate so that the two sets of data are not in conflict.

The relationship between plant metal concentrations and soil properties

Table 2 shows a matrix of correlations based on log-normally distributed abundance data for elemental concentrations in soils and one-year- and two-year-old wild plants from mine tailings at Les Malines. Considering the soils alone, all three elements tested (Cd, Pb and Zn) had concentrations (total and/or extractable) that were significantly correlated with each other except for extractable Cd vs. total Zn and total Pb. This is despite the fact that total Cd/Zn relationship (r=0.95) is by far the strongest in the set. The difference in extractability of two of the elements (11.6% of total for Cd and 5.7% of total for Zn) may explain why BCs (based on total concentrations) for Cd were in general higher than those for Zn except at very low concentrations of either element in the soil.

It is well known (e.g. Brown et al., 1994) that the pH of the soil is one of the most important factors governing elemental accumulation by plants. It will be noted from Table 2, that pH was inversely correlated with all elements in soils and with the same three metals in two-year-old plants. The pH vs. soil inverse correlations for extractable metals merely highlight the well-known fact that solubility of most elements in soils decreases when the pH is raised. It would appear however that only the two-year-old plants showed an inverse correlation between pH and elemental abundances in their tissues. It is clear that metal yields will be able to be increased by addition of acidifying agents such as sulphur or acidic fertilisers such as ammonium sulphate to the soils.

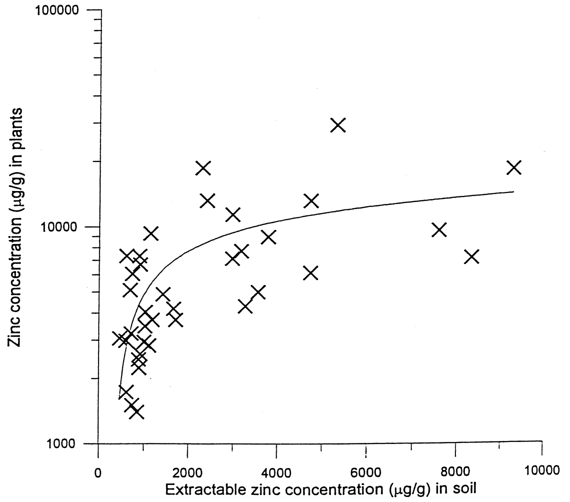

Figure 7. Uptake of zinc by specimens of *Thlaspi caerulescens* as a function of the extractable (1 M ammonium acetate) zinc content of the soil.

Despite the overriding effect of pH on metal uptake, it must be realised that the pH range of the Les Malines tailings was only 6.4-7.7 with a mean of 7.3. This mean was very close to that of the Auby soils (7.0) and allows for a certain degree of comparison between the two types of soil as well as allowing for meaningful observations on plant/soil relationships in the Les Malines region. This does not of course allow for other differences in the soils such as humus content and absorptive properties that would affect the bioavailability of metals.

The concentrations of Zn and Cd in both one-year- and two-year-old wild plants (Table 2) showed a highly or very highly significant correlation with the extractable metal content of the supporting soils. For plants raised in plant growth units, the correlation was less strong but nevertheless significant ($0.05 > P > 0.01$).

In the case of Pb in soils, relationships with the content of this metal in plants were inconclusive.

Figures 7 and 8 show the relationship between Zn and Cd concentrations in *Thlaspi* plants as a function of the corresponding concentrations in ammonium acetate extracts of the supporting soils. These plots do not differentiate between young and mature plants and for both elements show a trend towards limiting values of just over 1000 μg/g Cd and 10,000 μg/g (1%) Zn. The two plots are similar in shape to the plant/soil relationships for Auby soils (Figures 3 and 4) and appear to show a similar behaviour for both metals bioac-

Table 2. Correlation matrix for concentrations of total and extractable elements in soils ($n = 60$) and their corresponding values in one-year-old ($n = 20$) and two-year-old ($n = 40$) plants

	aCd	aPb	aZn	bCd	bPb	bZn	cCd	cPb	cZn	dCd	dPb	dZn
aPb	S*											
aZn	S*	S**										
bCd	S*	S**	S**									
bPb	NS	S**	S**	S**								
bZn	NS	S**	S**	S**	S**							
cCd	S**	NS	NS	NS	NS	NS						
cPb	NS	S*	S*	S*	NS	NS	NS					
cZn	S*	S*	S*	S**	NS	NS	NS	S**				
dCd	S*	NS	NS	NS	NS	NS	S**	NS	NS			
dPb	NS	S**	NS	NS	S*	NS	NS	NS	NS	NS		
dZn	NS	NS	S**	S*	NS	S*	NS	S**	S**	NS	NS	
pH	−S*	−S**	−S*	−S*	−S*	−S*	NS	NS	NS	−S*	−S*	−S*

[a] – extractable element in soil; b – total element in soil; c – one-year plants; d – two-year plants.
S** – very highly significant ($P < 0.001$); S* – highly significant ($0.001 < P < 0.01$); NS – not significant ($P > 0.01$).
NB – negative symbols imply an inverse relationship.

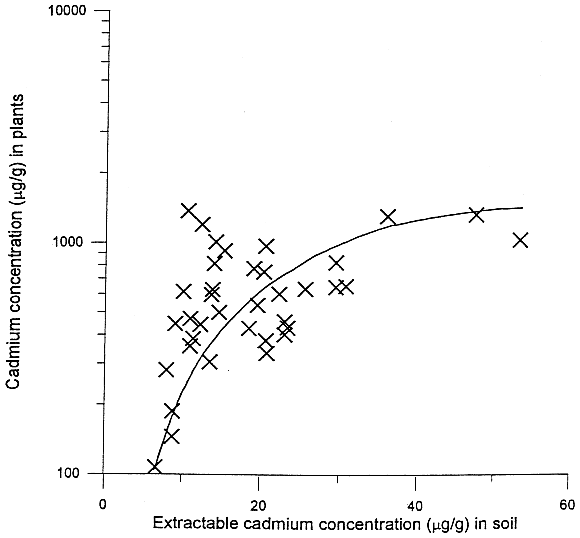

Figure 8. Uptake of cadmium by specimens of *Thlaspi caerulescens* as a function of the extractable (1 M ammonium acetate) cadmium content of the soil.

cumulated either from Auby soils contaminated by smelter emissions or from mine waste at Les Malines.

Potential of Thlaspi caerulescens *for phytoremediation*

For the successful practical application of phytoremediation a number of variables must be considered. Among the most important of these is the product of biomass and metal content of the plant material. This has been shown by Bennett et al. (1998) in experiments with *Thlaspi caerulescens* growing over base-metal mine waste. The product of biomass (weight of individual plants) and the Zn concentration in the plants rose from 22 μg for unfertilised specimens to 497 μg for plants fertilised with 50 μg/g nitrogen as calcium ammonium nitrate. The second variable to be considered is the time span (i.e. number of annual crops) needed to achieve the desired degree of remediation of the soil. In making these calculations it can not be assumed that all of the target element is plant-available. Adopting the conservative approach, however, that only half of the total metal content of the soils will be available to plants, we have calculated the total number of annual croppings of *T. caerulescens* needed to remove half of the metal burden of contaminated soils down to a depth of 15 cm assuming that the soil has a bulk density of 1.3. The plant is assumed to have a fertilised biomass of 5.2 t/ha and to contain 1.16% Zn and 0.16% Cd. These data are shown in Table 3.

Some of the values in Table 3 are of course extraordinarily high and have only been included for the sake of completeness. Any period of annual cropping exceeding 10 yr (or even less) would obviously be totally uneconomic. It should also be realised that the amounts of metal extracted may decrease after sequential crops (Brown et al., 1994), though not in proportion to the residual metal content of the soil. This factor has, however, already been allowed for in

Table 3. Total number of annual croppings required to remove half of the metal burden of contaminated soils using fertilised *Thlaspi caerulescens* plants with a biomass of 5.2 t/ha and containing 1.16% zinc and 0.16% cadmium in dry matter. The soil is assumed to have a density of 1.3 and to be penetrated by plant roots to a depth of 15 cm

Initial metal content (μg/g)	Mass of metal (kg)	Zinc	Cadmium
100,000 (10%)	150,000	1625	11,606
20,000 (2%)	30,000	325	2320
10,000 (1%)	15,000	163	1160
2000 (0.2%)	3000	33	231
1500 (0.15%)	2250	24	174
1000 (0.1%)	1500	16	116
500 (0.05%)	750	8.1	59
200 (0.02%)	300	3.3	23
100 (0.01%)	150	1.6	12
20 (0.002%)	30	0.33	2.3
10 (0.001%)	15	0.17	1.2
2 (0.0002%)	3	0.04	0.23

NB – It is assumed that only half of the metal content of soils is extractable. This conservative assumption also compensates for the fact that metal extraction decreases, though not in proportion, with sequential crops.

our conservative assumption that only half of the metal burden will be extractable. This implies that only contaminated soils with <500 μg/g Zn could be remediated to half this value within the limits of 10 years (actual time 8.13 years). This is somewhat lower than the 13 croppings suggested by McGrath et al. (1993) to reduce a soil content of 444 μg/g Zn to 300 μg/g but can be accounted for by the higher biomass reported by us for fertilised plants. It is obvious that it will never be economically feasible to remediate mine tips or heavily contaminated soils by phytoremediation if Zn is the target metal.

In the case of Cd, the problem is different. Much lower concentrations of Cd than of Zn, are to be expected in contaminated soils and the mean BC for *Thlaspi caerulescens* is much higher for Cd than Zn, except where the concentrations of both elements are <1 μg/g in the supporting soil. From Table 3, a burden of 500 μg/g Cd (hardly to be expected under natural conditions) would require just under 60 crops to be reduced to half this value. However, 20 μg/g could be reduced to 10 μg/g in just over 2 years and if the soil contained 10 μg/g Cd, a single crop would reduce this to nearly one half after only one year.

There is at present much concern worldwide about the steady build-up of Cd in soils from atmospheric deposition, application of sewage sludges and phosphatic fertilisers. Concentrations as high as 7 μg/g have been recorded in soils (Taylor and Percival, 1994) and it would seem that growing a crop of *Thlaspi caerulescens* might be an efficaceous and cost-saving option in specific cases. However, a few words of caution must be expressed with regard to this suggestion.

In suggesting that *T. caerulescens* might be used for phytoremediation of low levels of Cd (i.e. <2 μg/g) in soils, it is assumed that the BCs are a linear function of soil Cd concentration. This may not be the case (Brown et al., 1995a) so that the BCs reported here at high soil Cd concentrations are not likely to be applicable to lower Cd concentrations. It is also assumed that competition from weeds (never a problem over highly mineralised soils) could be controlled.

Because of the much higher phytotoxicity of Cd with respect to Zn, there is even the possibility of removing the former selectively from mine tailings in order to make the substrate more amenable to revegetation with other species.

A new and burgeoning technology in phytoremediation of contaminated soils involves the use of complexing agents such as EDTA in order to increase the solubility of metals. So far the emphasis has been on complexing of Pb (Huang and Cunningham, 1996), but a recent paper by Blaylock et al. (1997) has shown that addition of chelating agents to Indian mustard can be used to phytoremediate cadmium-contaminated soils. There is no reason why the same procedure should not be used to increase Zn uptake by *Thlaspi* or other plant accumulators. It is probable that saturation has already been reached by *Thlaspi* for Zn, but there should be some scope to increase the Cd uptake by this plant. If this could be achieved, the use of *Thlaspi caerulescens*, at least for phytoremediation of Cd contamination, will become an entirely feasible proposition.

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