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Thlaspi goesingense Hálácsy root plasticity in serpentine soils contradicts the metal foraging behavior

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Zusammenfassung

Der Ni Hyperakkumulator *Thlaspi goesingense* Hálácsy ist auf den Serpentinböden des südlichen Burgenlandes heimisch und speichert bis zu 12000 mg Ni kg^{-1} in der oberirdischen Biomasse. Mechanismen die zu diesem außerordentlichen Aufnahme- und Speicherverhalten führen sind noch nicht zur Gänze geklärt. Aktuelle Studien räumen dem „metal foraging“, einer metallorientierten Wurzelplastizität, eine wesentliche Bedeutung bei der Zn-Hyperakkumulation von *Thlaspi caerulescens* ein.

Die vorliegende Studie untersucht (1) die Bodenheterogenität von Serpentinböden als Voraussetzung für morphologische Wurzelplastizität sowie (2) das Wurzelwachstum von *T. goesingense* hinsichtlich veränderter morphologischer Eigenschaften als Antwort auf eine unregelmäßige Verteilung von Ni und Cr. Dazu werden eine Reihe von *T. goesingense* Pflanzen auf zwei unterschiedlichen Serpentinstandorten ausgewählt und jeweils durch vier systematisch gezogene Boden- und Wurzelproben charakterisiert.

Die bodenchemische Untersuchung zeigt eine deutliche Heterogenität in Bezug auf die Verteilung von Ni und Cr, sowohl zwischen den Standorten als auch innerhalb einzelner Wurzelsysteme. *T. goesingense* reagiert deutlich auf unterschiedliche Ni Konzentrationen vor allem durch eine Anpassung der Wurzellänge, während der durchschnittliche Wurzeldurchmesser keine signifikante Veränderung aufweist. Diese morphologische Wurzelplastizität belegt jedoch eine Strategie der Vermeidung hochkontaminierten Bodenregionen und widerspricht damit der Hypothese dass diese Form der Wurzelplastizität grundlegend zur Hyperakkumulation von Ni beiträgt.

Schlagwörter: Bodenheterogenität, Ni Hyperakkumulation, *Thlaspi goesingense*, Wurzelmorphologie, metallorientierte Wurzelplastizität

Summary

Thlaspi goesingense Hálácsy indigenous to a serpentine habitat in Redlschlag is known to hyper-accumulate Ni up to 12000 mg kg^{-1}. Recently root metal foraging has been proposed as one key mechanism involved in the hyperaccumulation of *Thlaspi caerulescens* expressing metallophilic root proliferation associated with increased Zn capture. This phenomenon is closely related to the heterogeneous distribution of metals typically found in natural field soils.

We aimed to verify the metal heterogeneity of serpentine soils postulated for plant foraging response and to assess *T. goesingense* root growth potentially indicating metallophilic root proliferation and morphological response. Two locations of a serpentine site in Redlschlag were selected differing in plant vegetation and soil characteristics. Soil cores containing root subsamples of *T. goesingense* were systematically taken at the edge of the plant rosettes. Ni (Cr) concentrations were examined and root growth and morphology assessed in the context of soil metal properties.

The evaluation of soil metal concentrations indicated variability of Ni and Cr concentrations, both between plots and within individual root systems. However metal variability was more stressed in scarcely vegetated soil on top of the quarry than in the woody sampling area. Morphological root characteristics of *T. goesingense* reflected soil metal heterogeneity particularly adapting root length. *T. goesingense* exhibited the ability to discriminate between soil patches of different metal concentrations by mechanisms of avoidance. Thus nickelphilic root foraging could not be observed in the current field study.

Keywords: heterogeneous soil, Ni hyperaccumulation, *Thlaspi goesingense,* root morphology, metal foraging

Introduction

Soil pollution by toxic levels of trace metals (heavy metals) and metalloids may derive from anthropogenic inputs such as atmospheric deposits and waste disposal from metal mining and processing industries as well as from geogenic sources, metalliferous parent material such as calamine ores (Cd, Pb, and Zn) or ultramafic rocks (Co, Cr, and Ni) (BAKER et al. 2000). These habitats are known to host a variety of metal hyperaccumulating plant species that characteristically accumulate metals more than 100 times larger than background concentrations in normal plant species (BAKER et al. 2000). Most common hyperaccumulator species belong to the *Brassicaceae* family including 23 *Thlaspi* species. For instance *Thlaspi goesingense* Hálácsy indigenous to serpentine soils in the area of Redlschlag is known to hyperaccumulate Ni concentrating up to 12000 mg kg^{-1} in shoot tissues.

Recently root foraging for Zn and Cd has been proposed as one key mechanism involved in the hyperaccumulation

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of *Thlaspi caerulescens* (HAINES 2002, WHITING et al. 2000) and *Sedum alfredii* (LIU et al. 2010). Root foraging is defined as "the process whereby an organism searches, or ramifies within its habitat, which enhances its acquisition of essential resources" (HUTCHINGS and JOHN 2003) and presupposes the ability of plants to discriminate between soil patches of different element concentrations. This trait is closely related to the heterogeneous distribution of metals typically found in natural field soils (DICKINSON and PULFORD 2005).

Hyperaccumulating plant species have initially inspired scientists to develop non-destructive *in-situ* phytoremediation technologies and to clean up metal affected soils by means of a phytoextraction approach (SALT et al. 1998, WENZEL et al. 1999). The metal extraction efficiency particularly depends on the accumulation potential and the biomass yield of the involved plant species. Moreover non-uniform pollutant distribution is known to affect the availability of metals to plant roots and thus alters the phytoextraction efficiency (KELLER et al. 2003). The ability of metal accumulators to discriminate between soil patches of different metal concentration levels and to express metallophilic root growth would reappraise their suitability for metalextraction processes.

In this study we aim to verify (1) metal heterogeneity of serpentine soils generally postulated for plant foraging response and (2) root growth and morphology of the hyperaccumulating *Thlaspi* species *T. goesingense* Hàlàcsy potentially indicating nickelphilic root proliferation. Soil Ni concentration levels will be examined in the root area of individual plants and root growth and morphology assessed in the context of total and extractable soil Ni (Cr) concentrations.

Materials and Methods

To this end a serpentine quarry in Redlschlag (WENZEL and JOCKWER 1999) naturally hosting *Thlaspi goesingense* Hàlàcsy was sampled selecting two plots obviously differing in soil vegetation. The first plot (Quarry, Q) on top of the quarry showed poor additional vegetation due to anthropogenic disturbance whereas the second one (Wood, W) was loosely wooded with pines and oaks. Soil was generally characterized as an Eutric Leptosole due to the ultramafic parent material.

End of May overall 20 *T. goesingense* plants were sampled, systematically taking four soil cores at the edge of each plant rosette (depth 25 cm; section 5 cm). Roots were carefully removed from the excavated soil cores, weighed and stained for root scanning according to HIMMELBAUER et al. (2005). Data were finally processed with the WinRhizo (Regents Instruments; Canada) program to evaluate root length (RL) and the average root diameter (avgRD). Soil samples were sieved to < 2 mm and further processed to evaluate total (HCl:HNO_3-digest) and extractable (1 M NH_4NO_3-extract) Ni and Cr concentrations. Analytes were measured by means of ICP-MS (Elan 9000 DRCe, Perkin Elmer).

Statistical analyses based on t-Tests to evaluate significant differences between means ($p \leq 0.05$) particularly in respect to differences between the sample plots Quarry and Wood. To verify the variance of root parameters of individual plants and soil metal concentrations within root systems coefficients of variation (CV %) were calculated. The whole data set was further examined using a basic correlation matrix (Statistica 6).

Results and Discussion

Soil Ni concentrations considerably differed between the sampled plots and generally higher concentrations were found for the Quarry (Q) compared to Wood (W) (*Figure 1*). Similar to Ni, serpentine soil in Redelschlag concentrated high levels of Cr (total concentration values of 2033 (Q) and 2642 mg kg^{-1} (W) and 0.012 (Q) and 0.032 mg kg^{-1} (W) in soil extracts). However Cr concentrations in Wood soils significantly exceeded soil concentration values of the Quarry (Q) soil samples. These differences were particularly shown for the NH_4NO_3 extractable Cr concentrations (data not shown).

Mean coefficients of variance (CV %) calculated for Quarry and Wood soils did not differ remarkably (*Table 1*). However, the variability of metal concentrations within individual root systems was more pronounced on top of the quarry compared to the woody sampling plot.

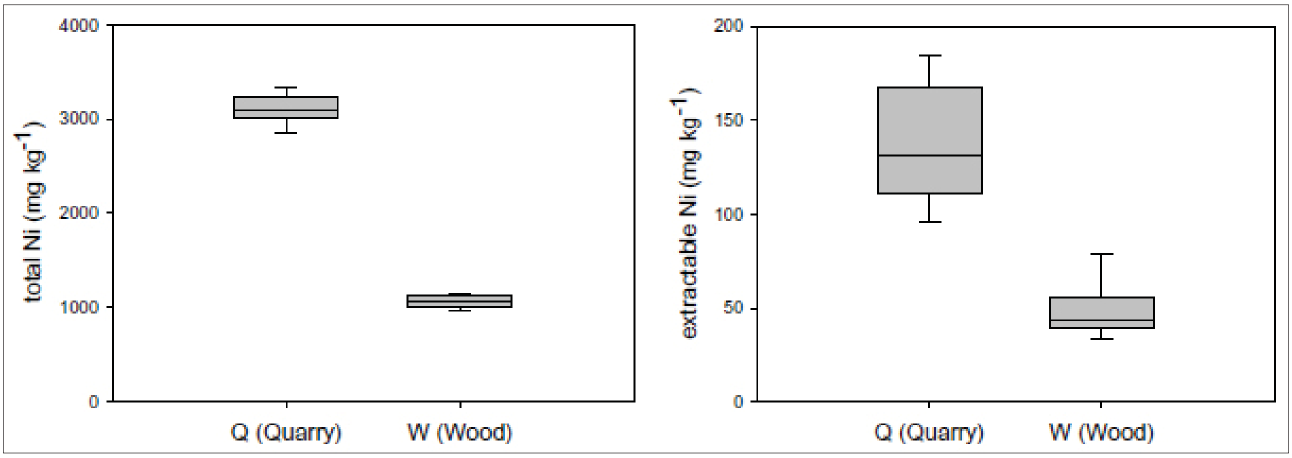

Figure 1: **Boxplots of total and extractable soil Ni concentrations of the sampling plots Quarry and Wood.**

Table 1: **Mean CV % values (coefficient of variance) of soil metal concentrations and root properties calculated for the experimental plots "Quarry" and "Wood" based on CVs (%) of individual plants.**

	Soil metal concentrations				Root properties		
CV [%]	**Ni**		**Cr**		**BM**	**RL**	**avgRD**
	total	extractable	total	extractable	biomass	root length	average root diameter
Quarry	5.11	23.04	6.17	29.13	113.70	78.72	40.09
Wood	3.75	11.73	5.92	15.41	107.79	47.50	59.07

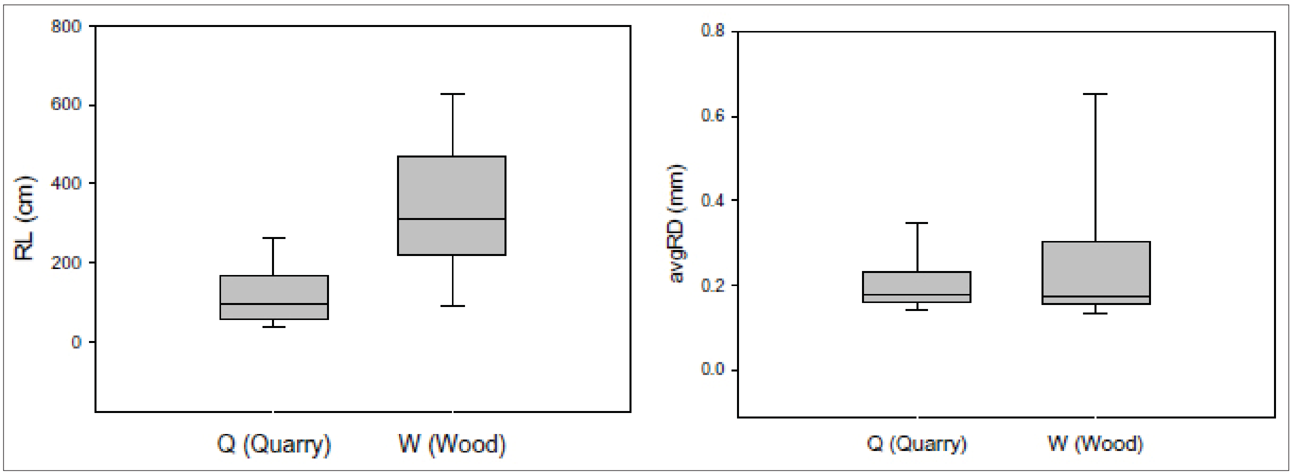

Figure 2: **Boxplots of root length (RL) and average root diameter (avgRD) of the sampling plots Quarry and Wood.**

Data on root biomass removed from soil cores (data not shown) and respective morphological characteristics did not significantly differ between sample plots (*Figure 2*) even so root characteristics were more variable within individual root systems than chemical soil properties (*Table 1*).

The variability of root morphological parameters may have been induced by the genetic diversity of *T. goesingense* or the heterogeneity of various parameters in natural field situation. However our experimental data suggest non-uniform distribution of Ni and Cr that affected root morphological variability. Statistical analyses significantly revealed correlations between plant parameters dry weight and root length with soil Ni and Cr concentrations. Correlations were particularly stressed for RL in regard of total Ni (R^2= -0.52; R^2= -0.46) and extractable Ni (R^2= -0.53; R^2= -0.53) indicating *T. goesingense* to reduce root proliferation towards highly Ni enriched soils patches.

The comparison of root lengths and Ni concentrations observed in soil cores of individual plants revealed highest root lengths in soil cores with lowest Ni concentration levels. These data suggest *T. goesingense* to discriminate between soil patches of different Ni concentrations, however, expressing an avoidance mechanism. Thus root morphology obviously contradicts the metallophilic foraging behavior as observed for *T. caerulescens* in response to non-uniform Zn distribution (HAINES 2002).

Plant root parameters were occasionally correlated with Cr indicating increased root length with reduced metal concentrations ($+0.41<R^2<+0.50$). Statistical analyses further proved the significance of correlations between root biomass and soil metal concentrations. However coefficient values were below those observed for root length. Moreover *T. goesingense* average root diameter was hardly correlated with soil metal concentrations.

Conclusions

The evaluation of soil metal concentrations of a serpentine habitat in Redlschlag indicated variability of Ni and Cr concentrations, both between plots (Quarry and Wood) and within individual root systems. Metal variability was more stressed in scarcely vegetated soil on top of the quarry (Quarry) than in forest soil (Wood). Morphological root properties of the Ni hyperaccumulator *T. goesingense* indigenous to this sampling site reflected soil metal heterogeneity particularly adapting root length. *T. goesingense* showed discrimination properties between soil patches of different metal concentrations but expressed mechanisms of avoidance. Thus nickelphilic root foraging could not be observed in the current field study.

References

BAKER, A.J.M., S.P. MCGRATH, R.D. REEVES and J.A.C. SMITH, 2000: Metal Hyperaccumulator Plants: A Review of the Ecology and Physiology of a Biological Resource for Phytoremediation of Metal-Polluted Soils. In Phytoremediation of Contaminated Soil and Water. Eds. N Terry and G Banuelos. pp 85-108. Lewis Publishers, Boca Raton.

DICKINSON, N.M. and I.D. PULFORD, 2005: Cadmium phytoextraction using short-rotation coppice Salix: the evidence trail. Environmental International 31, 609-613.

HAINES, B.J., 2002: Zincophilic root foraging in *Thlaspi caerulescens*. New Phytologist, 363-372.

HIMMELBAUER, M.L., M. PUSCHENREITER, A. SCHNEPF, W. LOISKANDL and W.W. WENZEL, 2005: Root morphology of *Thlaspi goesingense* Hálácsy grown on a serpentine Soil. Journal of Plant Nutrition and Soil Science-Zeitschrift für Pflanzenernährung und Bodenkunde 168, 138-144.

HUTCHINGS, M.J. and E.A. JOHN, 2003: Distribution of roots in soil, and root foraging activity. In Root ecology. Eds. H d Kroon and E J W Visser. pp 33-60. Springer, Berlin, Heidelberg.

KELLER, C., D. HAMMER, A. KAYSER, W. RICHNER, M. BRODBECK and M. SENNHAUSER, 2003: Root development and heavy metal phytoextraction efficiency: comparison of different plant species in the field. Plant and Soil 249, 67-81.

LIU, F., Y. TANG, R. DU, H. YANG, Q. WU and W. QIU, 2010: Root foraging for zinc and cadmium requirement in the Zn/Cd hyperaccumulator plant *Sedum alfredii*. Plant Soil 327, 365-375.

SALT, D.E., R.D. SMITH and I. RASKIN, 1998: Phytoremediation. In Annual Review of Plant Biolog, pp 643-668.

WENZEL, W.W. and F. JOCKWER, 1999: Accumulation of heavy metals in plants grown on mineralized soils of the Austrian Alps. Environmental Pollution 104, 145-155.

WENZEL, W.W., D.C. ADRIANO, D. SALT and R. SMITH, 1999: Phytoremediation: A Plant-Microbe-Based Remediation System In Bioremediation of Contaminated Soils. Eds. D C Adriano, J-M Bollag, W T F Jr and R C Sims. pp 457-508. Agronomy Madison, USA.

WHITING, S.N., J.R. LEAKE, S.P. MCGRATH and A.J.M. BAKER, 2000: Positive responses to Zn and Cd by roots of the Zn and Cd hyperaccumulator *Thlaspi caerulescens*. New Phytologist 145, 199-210.