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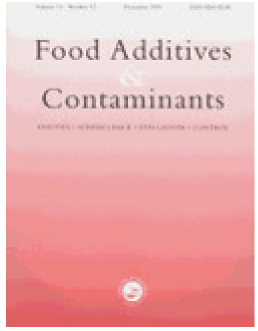

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Uptake of Thallium from Naturally Contaminated Soils into Vegetables

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Abstract

Thallium transfer from naturally (pedogeochemically) contaminated soils into vegetables was studied. Three different types of top-soil (heavy medium and light) were used for pot experiments. The soils were collected from areas with low, medium and high levels of pedogeochemical thallium (0.3 1.5 and 3.3 mg kg^{-1}). The samples of vegetables were collected and analysed. The total content of thallium in soil and the type of soil (heavy, medium, and light), plant species and plant variety were found to be the main factors influencing thallium uptake by plants. The uptake of thallium from soils with naturally high pedogeochemical content of this element can be high enough to seriously endanger food chain. These findings are very important because of the high toxicity of thallium and the absence of threshold limits for thallium in soils, agricultural products, feedstuffs and foodstuffs in most countries, including the the Czech Republic

Introduction

Thallium is a rare and dispersed element with a geochemical behaviour very near to K and Rb (Rehkämper and Nielsen 2004). Thallium can mimic potassium in metabolic processes (Tremel et al. 1997a) because of similar ionic radii (Tl 170 pm K 164 pm and Rb 172 pm) and it can be found in micaceous minerals (Shannon 1976). But thallium displays also chalcogenic behaviour and can be found in some sulphide minerals and in sulphur containing ores (Merian 1991; Sager 1998; Jones et al. 1990).

The acute and chronic toxicity of thallium (Tl) is similar to the toxicity of cadmium, mercury and lead (Sager 1998; Sáňka et al. 2000). Thallium is toxic to all organisms in both, monovalent and trivalent form. Human exposure to this element can result in harmful effects including death. Intoxication is associated with disorders of the nerve and digestion systems and Na/K metabolism. Symptoms include polyneuropathy and loss of hair (Repetto et al. 1998). In adults oral lethal doses of thallium are estimated to range between 6 and 40 mg kg^{-1} with an average dose of 10-15 mg kg^{-1} (ATSDR 1999; Ewerts 1988). In spite of the potential toxicity to animals and humans thallium has received only little attention.

Common thallium contents in mafic rocks range from 0.05 to 0.4 mg kg^{-1} and in acid rocks from 0.5 to 2.3 mg kg^{-1}. Calcareous sedimentary rocks contain as little as 0.01 to 0.14 mg kg^{-1} Tl (Kabata-Pendias and Pendias 2001). The median content of thallium 0.29 mg kg^{-1} and the maximum more than 50 mg kg^{-1} were found for French soils (Tremel et al. 1997a; Tremel et al. 1997b). Content of thallium in soils in the range from 1.5 to 6.9 mg kg^{-1} was reported in China in the area of natural Tl-rich sulphide mineralization (Xiao et al. 2004). It was found that pedogeohemical concentration of thallium in some areas of the Czech Republic is more than ten times higher than the median of the values (maximum 3.7 mg kg^{-1}; median 0.25 mg kg^{-1}). No anthropogenic contamination was proved and higher thallium contents were only of pedogeochemical origin (Zbíral et al. 2000; Zbíral et al. 2002; Pavlíčková et al. 2003; Bunzl 2001; Dmowski and Budarek 2002; Medek et al. 2001). The highest contents of this element were found in soils derived from granite (2 - 4 mg kg^{-1}) or paragneiss (0.5 - 1 mg kg^{-1}).

Anomalous levels of thallium in soils are derived from soil substrate or from an anthropogenic contamination (LaCoste et al. 1991). Ore smelting (Olkusz and Bokowo, Poland; Lanmuchang Metallogenic Belt, China), cement production (Lengerich, Germany) and combustion of fossil fuels are the main anthropogenic sources of soil contamination (Jones et al. 1990; Kemper et al. 1991; Lustigman et al. 2000; Lin et al. 1999a; Lin et al. 1999b; Sager 1986; Wierzbicka et al. 2004).

Uptake of thallium by different plants was studied mainly on anthropogenically contaminated soils or in the field and pot experiments after addition of thallium. It was found that plants exhibit species dependent preferences (Xiao et al. 2004) and particularly brassicaceous plants can reach very high concentrations of thallium in their tissues without any symptoms of phytotoxicity. *Iberis intermedia Guers.* and *Biscutella laevigata L.* can have thallium concentration above 1 % dry matter (DM) and can be used for phytoremediation or phytomining of thallium (Anderson et al. 1999). Kale (*Brassica oleracea acephala* L. cv. Winterbor) was found to have behaviour of thallium hyperaccumulating plant (Husam et al. 2003). Selection of suitable cultivars with low thallium uptake can contribute to reduce the food chain contamination. There were observed only small differences between the studied varieties for rape but there were differences more than twenty fold for the kale varieties (Kurz et al. 1999). Some authors studied equilibrium establishment between plant available and plant non-available fractions of thallium in soils (Pavlíčková et al. 2005). They proved that the equilibrium is soil dependent and diffusion driven process. Plants (especially brassicaceous) can accumulate much more thallium than determined as a plant available fraction by extraction of soil with some weak extractants.

LaCoste et al. (LaCoste et al. 1991) tested 11 vegetables in pot trials for two levels of soil Tl. 36 crops including 3 wild plants were planted on soils with the thallium content from 1.5 to 6.9 mg kg^{-1} (soils were derived from the thallium rich sulphide ores). In both cases authors proved very strong species dependent preferences in thallium uptake. Contents up to 495 mg kg^{-1} were found in green cabbage (Xiao et al. 2004). Tremel and Mench (Tremel and Mench 1998) recommended monitoring of rape cattle cakes and brassicacea fodders for thallium content because their study demonstrated strong possibility of plant contamination by thallium of pedogeochemical origin. Rape (*Brassica napus* L.) was tested on soils with different content of added thallium and also on soils with higher pedogeochemical content of this element. Higher transfer of thallium was observed in the case of artificially contaminated soils. But the uptake of thallium from soils with naturally high content of thallium was found to be high enough to seriously endanger food chain (Zbíral et al. 2000; Zbíral et al. 2002; Pavlíčková et al. 2003; Medek et al. 2001; Pavlíčková et al. 2005).

No recommended maximum values are available at the present time in most countries. In Germany 0.46 – 2.24 mg kg^{-1} DM (or 0.4 - 2 mg kg^{-1} 88% DM) was established for feed (anonymous 1997; ananymous 1998). We can take thallium concentration 0.4 - 2 mg kg^{-1} DM for fodder crops and 0.25 – 0.5 kg^{-1} DM for food as a provisional working limit. The values 0.25 and 0.4 mg kg^{-1} DM were used for the evaluation of our results. Our study was focused on two areas in the Czech Republic with naturally higher contents of thallium found in our preliminary studies (Sáňka et al. 2000; Zbíral et al. 2000; Zbíral et al. 2002; Pavlíčková et al. 2003; Medek et al. 2001; Pavlíčková et al. 2005). The main goal was to find suitable crops that can be planted in these areas without contamination of food chain by thallium and also to find plants that should be avoided in the areas because of their ability to accumulate thallium in their tissues.

MATERIALS AND METHODS

Instruments

Plant samples (except rape seeds) were finely ground using a high-speed mill Grindomix (Retsch, Germany) and digested by nitric acid in the closed high-pressure microwave system (Ethos SEL, Milestone, Italy). Dry matter (DM) was determined (2 g of a sample 105 ºC) using a MA 30 moisture analyser (Sartorius GmbH, Goetingen, Germany). A sixteen-position double heating block with digestion tubes and coolers MB 422 BH (Uni Elektro, Hradec Králové, Czech Republic) was applied for soil digestion. A sub-boiling distillation unit BSB-939-IR (Berghof BSB-939-IR, Germany) was used for purification of nitric acid. ICP-MS ELAN 6000 (Perkin-Elmer SCIEX, Norwalk, USA) with a cross flow nebulizer Scott's type spray chamber and Gilson 212 peristaltic pump was used for determination of Tl. The MS part was regularly checked by a calibrating solution (Perkin-Elmer SCIEX, Norwalk, USA). The operating parameters were identical with those given in the previous papers (Zbíral et al. 2000; Zbíral et al. 2002; Pavlíčková et al. 2003; Medek et al. 2001; Pavlíčková et al. 2005). Operational parameters of the instruments are given in Table 1.

Reagents.

All reagents and standard solutions were prepared using Milli Q deionised water (Millipore, Bedford, USA). All chemicals were of reagent grade purity purchased from (Analytika, Prague, Czech Republic) and Merck (Darmstadt, Germany). Stock standard solutions 1000 ± 2 mg L^{-1} Tl in 2% (v/v) nitric acid and 1000 ± 2 mg L^{-1} Lu in 2% (v/v) nitric acid (Analytika, Prague, Czech Republic) were used for preparing of calibrating standard solutions.

Pot experiments

Soils with different pedogeochemical contents of Tl. Three different soils were collected - Nivnice (heavy soil - HS 0.3 mg Tl kg^{-1} DM), Heřmanice (medium soil - MS 1.5 mg Tl kg^{-1} DM) and Lužice (light soil - LS 3.3 mg Tl kg^{-1} DM). The content of thallium (expressed as mg Tl kg^{-1} of dry matter - DM) in all cases was only of pedogeochemical origin. Basic characteristics of the soils are summarised in Table 2. 7.5 kg of air-dried soil (particles less than 2 cm) were used for filling a pot. Six replicates for each soil and each plant (90 pots for the experiment) were used. Five crops - spring rape, winter rape, kale, kohlrabi and maize were tested in the first year and celery, parsley, carrot, and onion were tested in the same pots next year (for the scheme of the experiment see Table 3). Winter rape was sowed in each pot in August. Normally developed plants were singled out in September. Other crops were sowed in April and singled out in May. The fully matured plants were harvested in July. The soils were fertilized with N (NH_4NO_3), P ($CaHPO_4$.2 H_2O) and K (KCl) according to the individual demands of each crop to provide a sufficient nutrient supply. The pots were protected against rain during the whole period. Soil moisture was adjusted to 60% of maximum water capacity by daily watering with deionized water. During the harvest the plant parts were collected separately weighed and stored for analysis.

Sample preparation and digestion.

Plant samples were mechanically cleaned immediately after the harvest and subsequently by a quick washing with deionised water to remove the rest of soil and dust particles. Plant samples were dried and finely ground. The rapeseeds were analysed without grinding. The all samples (1 g) were digested by nitric acid (8 ml HNO_3 and 10 ml H_2O) in the microwave digestion system at 145 ºC and 700 W for 5 min 180 ºC and 600 W for another 5 min and finally at 180 ºC and 1000 W for the next 5 min. The digests were adjusted to the final volume of 50 ml with deionized water. The digests were further diluted 1-20 times by deionized water before the ICP/MS measurement. Each series consisted of a suitable amount of samples given by the procedure one internal reference standard and two blanks.

Soil samples were air-dried gently crushed and sieved. Fraction < 2 mm according to ISO 11464 was used for the analysis. Soils were digested (Pavlíčková et al. 2003) by HNO_3-H_2O_2 (2 g soil sample 10 ml HNO_3 and 20 ml H_2O_2 were used boiling for four hours under cooler). Soil extracts were diluted 5 - 10 times by deionized water before the ICP/MS determination. Each series consisted of a suitable number of samples given by the procedure two internal reference standards and two blanks.

Determination of thallium by ICP/MS.

Single element calibrating standard solutions were used for calibration of the ICP/MS instrument at five different concentrations of thallium (0, 1, 5, 10 and 50 µg L^{-1}). Lutetium at the concentration 10 µg L^{-1} was used as an internal standard (^{175}Lu signals). The extraction agents acids and lutetium concentrations in the standard calibrating solutions matched their concentrations in the sample solutions. The calibration curve was linear in the whole calibrating range ($r \geq 0.9999$). Limit of detection 1.2 µg kg^{-1} was achieved for the samples (3 S/N criterion). Thallium content was determined from ^{205}Tl signal.

RESULTS AND DISCUSSION

The results of the pot experiments are given in Tables 4 and 5 for Brassicaceous plants and the other crops respectively. The contents of thallium in different parts of the crops for all three investigated soils are given in Figure 1. Average total uptake of thallium from the experimental pot did not follow exactly the concentration of thallium in soil. Uptake of thallium from the light soil (Lužice) with the highest content of thallium (3.3 mg kg^{-1}) was ten times higher than from both other soils.

The bioaccumulating factor - BAF (concentration of thallium in plant (or its part)/concentration of thallium in soil) reflects thallium availability from the given soil. The highest bioaccumulating factors were found for the light soil (Lužice) and than for the heavy soil (Nivnice). Thallium in medium soil (Heřmanice) in spite of its relatively high level (1.5 mg kg^{-1}) was found to be less available. BAFs for non-brassicaceous plants were usually below 0.1 even for the soil from Lužice. Higher BAFs for these plants were observed for green parts of vegetables (onion, carrot, parsley) than for other parts. Celery was the only exception of this rule. The situation was substantially different for plants of the Brassicaceae family. BAFs for spring and winter rape were near 1 as found also in the previous studies focused on this crop (Zbíral et al. 2000; Zbíral et al. 2002; Pavlíčková et al. 2003; Medek et al. 2001; Pavlíčková et al. 2005). BAFs higher than 0.4 were found for the other tested brassicaceous plants (except for stalk of kale and kohlrabi). BAF 2.6 was observed as high as for the green part of kohlrabi.

The translocation factor – TLF (the ratio of thallium concentration in different parts of the plant) shows that for most crops (brassicaceous and others) higher thallium concentration is located in the green part of the plant. The highest TLF was found for kohlrabi (19), kale (10), but also for onion (10) and carrot (8). Concentration of thallium in celeriac part of celery was found to be higher than in the green part.

If we take thallium concentration 0.4 - 2 mg kg^{-1} DM for fodder crops and 0.25 – 0.5 kg^{-1} DM for food as a provisional working limit and adopt 0.25 and 0.4 mg kg^{-1} for the evaluation (anonymous 1997; anonymous 1998) it can be concluded that for heavy soils from Nivnice, and (a bit surprisingly) medium soils (Heřmanice) most crops and their parts were below the limit. Straw of spring rape was above the limit and leaves of kale just on the limit for food on medium soil (Heřmanice). The green part of kohlrabi was able to accumulate thallium even from soil with only a background content of thallium and this part of plant proved to be unsuitable for food or feed for all investigated soils. Brassicaceous plants grown on light soil (Lužice) substantially exceeded the limits with only one exception – stalk of kale. Non-braccicaceous crops showed also relatively high concentration of thallium on light soil (Lužice). The celeriac part of celery and the green part of parsley exceeded the limit for food and the green parts of carrot and onion exceeded the limit for feed.

CONCLUSIONS

The total content of thallium in soil, physico-chemical form and form of binding to soil particles seem to be the main factors influencing the uptake by a plant. From the data presented hereby it can be seen that thallium is an exception since the values obtained for other elements in all vegetables are significant smaller than the corresponding plant-soil concentration ratios for the uncontaminated soil. These results demonstrate quantitatively that the ability of a plant to accumulate a metal compared to a control soil might not exist for an anthropogenically contaminated soils and vice-versa. In addition thallium can be present as Tl(I) or Tl(III) which makes it necessary to distinguish between these two species (Lin et al. 1999a; Lin et al. 1999b). Without this specification a correct toxicological evaluation is not possible particularly since Tl(I) possibly occurs in soluble whereas T(III) in colloidal form.

Uptake of thallium by plants is species dependent. Plant varieties and plant parts differ in the degree of uptake and accumulation of Tl. Some brassicaceous plants commonly grown as vegetables behave as hyperaccumulators of Tl. Content of thallium in different aerial parts of tested plants can differ substantially (nearly 20 times in maximum). The highest concentration was observed mainly in the green parts of the particular plants. Green part of kohlrabi can contain thallium in concentration exceeding the provisional limit even if grown on soil with very low natural content of Tl.

The concentration of thallium in vegetables in many cases can substantially exceed the concentration of thallium in soils. Thus thallium content should be monitored and the plants with high thallium accumulation power should be excluded from growing for human or animal nutrition in contaminated areas. The above mentioned facts are often neglected because legal measures are usually taken only for the areas anthropogenically contaminated as a result of a human activity. Uptake of thallium from soils with naturally high content of thallium can be high enough to seriously endanger food chains (directly by consumption of plants grown on contaminated soils indirectly by consumption of meat from animals feed by rape cattle cakes a by-product of rapeseed oil production).

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REFERENCES

Anderson CWN, Brooks RP, Chiarucci A, LaCoste CJ, Leblanc M, Robinson BH, Simcock R, Stewart RB. 1999. Phytomining for nickel, thallium and gold. J. Geochem. Explor. 67:407-415.

Anonymous. 1997. Anlage 5 (zu §§ 23 24 und 25) der Futtermittelverordnung in der Fassung vom 19. November 1997. BGBL I Nr. 77 vom 24. November 1997 2714.

Anonymous. 1998. Maximale Immissions-Werte fű̃r Thallium zum Schutz der Landwirtschaftlichen Tiere. VDI – Richtlinie 2310 Blatt 29 (E). VDI/DIN – Handbuch Reinhaltung der Luft. Band 1a.

ATSDR Toxicological Profiles for Thallium. 1999. Roper WL. (Ed.). CRC Press, Boca Raton: p. 57.

Bunzl K, Trauttmannsheimer M, Schramel P, Reifenhauser W. 2001. Availability of arsenic copper lead thallium and zinc to various vegetables grown in slag-contaminated soils. J. Environ. Qual. 30:934-939.

Dmowski K, Badurek M. 2002. Thallium content in selected plants and fungi in the vicinity of the Boleslaw zinc smelter in Bukowo (Poland). A preliminary study. Acta Biol. Cracov. Bot. 44:57-61.

Ewers U. 1988. Environmental exposure to thallium. Sci. Total Environ. 71:285-292.

Husam Al Najar, Schulz R, Rőmheld V. 2003. Plant availability of thallium in the rhizosphere of hyperaccumulator plants: a key factor for assessment of phytoextraction. Plant Soil 249:97-105.

Jones KE, Lepp NW, Obbard JP. 1990. Thallium. In: Alloway JB. (Ed.) Heavy Metals in Soils. J. Wiley & Sons, New York: pp. 304 - 309.

Kabata-Pendias A, Pendias H. 2001. Trace elements in soils and plants. CRC Press, LLC 3rd Ed. Florida: pp. 183-185.

Kemper FH, Bertram HP. 1991. Thallium. In Metals and their Compounds in the Environment. Merian E. (Ed.). VCH. Weinhaim (FRG): pp. 1227-1241.

Kurz H, Schulz R, Rőmheld V. 1999. Selection of cultivars to reduce the concentration of cadmium and thallium in food and fodder plants. J. Plant Nutr. Soil Sci. 162:323-328.

LaCoste Ch, Robinson B, Brooks R. 2001. Uptake of thallium by Vegetables: Its significance for human health phytoremediation and phytomining. J. Plant Nutr. 24:1205-1215.

Lin TS, Nriagu J. 1999a. Thallium speciation in the Great Lakes. Environ. Sci. Technol. 33:3394-3397

Lin TS, Nriagu J. 1999b. Thallium speciation in river waters with Chelex-100 resin**.** Anal. Chim. Acta 395:301-307.

Lustigman B, Lee HL, Morata J, Khan F. 2000. Effect of Thallium on the Growth of Anacystis nidulans and Chlamydomonas reinhardtii. Bull. Environ. Contam. Toxicol. 64:565-573.

Medek P, Pavlíčková J, Zbíral J, Čižmárová E, Kubáň V. 2001. Inductively Coupled Plasma Mass Spectrometric Determination of Thallium in Soils and Winter Rapeseeds. Intern. J. Environm. Anal. Chem. 81:207-219.

Merian E (Ed.).1991. Metals and Their Compounds in the Environment. Occurrence Analysis and Biological Relevance. VCH Weinheim, New York.

Pavlíčková J, Zbíral J, Čižmárová E, Kubáň V. 2003. Comparison of Aqua Regia and HNO_3+H_2O_2 Procedures for Extraction of Twenty One Elements from Soils. Anal. Bioanal. Chem. 376:118-125.

Pavlíčková J, Zbíral J, Smatanová M, Houserová P, Čižmárová E, Havlíková Š, Kubáň V. 2005. Uptake of Thallium from Artificially and Naturally Contaminated Soils into Rape (Brassica napus L.). J. Agric. Food Chem. 53:2867-2871.

Rehkämper M, Nielsen SG. 2004. The mass balance of dissolved thallium in oceans. Mar. Chem. 85:125-139.

Repetto G, del Peso A, Repetto M. 1998. Human thallium toxicity. In: Nriagu JO. (Ed.). Thallium in the Environment. Wiley, New York: pp. 167-199.

Sager M. 1998 Thallium in agricultural practice. In: Nriagu JO. (Ed.). Thallium in the Environment. Wiley, New York: pp. 59-87.

Sager M. 1986. Trace Analysis of Thallium. (In German). Georg Thieme Vrlg: Stuttgart FRG.

Sáňka M, Němec P, Havlíková Š. 2000. Evaluation of thallium content in arable spoil and its influence on quality of agricultural production. (In Czech). ÚKZÚZ, Brno, Czech Republic.

Shannon RD. 1976. Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. Acta Crystallogr. A 32:751-767.

Tremel A, Masson P, Sterckeman T, Baize D, Mench M. 1997a. Thallium in French Agrosystems - I. Thallium Contents in Arable Soils. Environ. Pollut. 95:293-302.

Tremel A, Masson P, Garraud H, Donard OXF, Baize D, Mench M. 1997b. Thallium in French agrosystems - II. Concentration of thallium in field-grown rape and some other plant species. Environ. Pollut. 97:161-168.

Tremel A, Mench M. 1998. Study of the mobility bioavailability and phytotoxicity of thallium from non-point sources. INRA, Villenave d'Ornon (France).

Wierzbicka M, Szarek-Lukaszewska G, Grodzińska K. 2004. Highly Toxic Thallium in Plants from The Vicinity of Olkusz (Poland). Ecotox. Environm. Safety 59:84-88.

Xiao T, Guha J, Boyle D, Liu C-Q, Chen J. 2004. Environmental Concerns related to high Thallium Levels in Soils and Thallium uptake by Plants in Southwest Guizhou China Sci. Tot. Environm. 318:223-244.

Zbíral J, Medek P, Kubáň V, Čižmárová E, Němec P. 2000. Determination of Thallium in Aqua-regia Soil Extracts by ICP-MS. Commun. Soil. Sci. Plant Anal. 31:2045- 2051.

Zbíral J, Pavlíčková J, Havlíková Š, Čižmárová E, Němec P, Sáňka M, Kubáň V, Medek P. 2002. Comparison of Several Soil Extractants for Determination of Thallium. Commun. Soil Sci. Plant Anal. 33:3303-3312.

Caption to figure

Fig. 1. Relationship between content of thallium [in mg kg^{-1} DM] in the soil and its uptake by separate parts of the test plants [in mg kg^{-1} DM] for Brassicaceous family (bottom) and the other crops (top) respectively.

386 Table 1. Operational parameters of Elan 6000 ICP-MS
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Parameter	Value	Parameter	Value
Rf Power	1050 W	Readings/Replicate	1
Nebulizer Gas Flow	0.94 L min^{-1}	Number of Replicates	5
Lens Voltage	7.3 V	Measurement Mode	Peak hopping
Detector	Dual mode	Sample Flow Rate	1 mL min^{-1}
Sweeps/Readings	10	Dwell Time of Isotopes	100 ms

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Table 2. Basic Characteristics of Topsoils [a] Used for Pot Experiments (All Data Given for DM)

Parameter	Unit	Nivnice	Heřmanice	Lužice
Tl [b]	mg kg $^{-1}$	0.3	1.5	3.3
pH/$CaCl_2$		6.9	6.1	6.4
P [c]	mg kg $^{-1}$	105	310	62
K [c]	mg kg $^{-1}$	798	702	174
Mg [c]	mg kg $^{-1}$	281	152	636
Ca [c]	mg kg $^{-1}$	4730	2260	2520
Fraction < 10 µm	%	54.3	22.1	17
Fraction < 1 µm	%	32.5	7.2	5.2
Fraction 1-10 µm	%	21.8	14.9	11.8
Fraction 10-50 µm	%	20.8	16.9	16.3
Fraction 50-250 µm	%	17.7	18.9	27.4
Fraction 0.25-2 mm	%	7.2	42.1	39.3
Nitrogen (tot.)	%	0.25	0.18	0.17
Cox[d]	%	1.79	2.29	1.72
TEC[e]	mM.kg^{-1}	410	405	368

[a] Nivnice (heavy soil) Heřmanice (medium soil) and Lužice (light soil).

[b] Content in H_2O_2 - HNO_3 extract. [c] Content according to Mehlich 3. [d] oxidized forms of carbon. [e] total exchange capacity of the soils

Table 3. Species and Cultivars Used in Experiments

Plant[1]	**Species**	**Cultivar**[2]	**Pot**[3]	**Symbol**[4]
Maize[5]	*Zea mays* L.	Cemilk H285	12/4	A
Celery[6]	*Apium graveolens* var. Rapaceum	Maxim	-/2	A
Parsley[6]	*Petroselinum crispum* cvar. Erfurtense	Dobra	20/8	B
Carrot[6]	*Daucus carota* L.	Berjo	20/8	C
Onion[7]	*Allium cepa* L.	Všetana	-/6	D
Spring rape[8]	*Brassica napus* L. cvar. *Napus*[9]	Golda	20/10	E
Winter rape[8]	*Brassica napus* L. cvar. *Napus*	Zoro	20/10	D
Kale[8]	*Brassica oleracea* L. var. Acephala	Winterbor F1	6/2	B
Kohlrabi[8]	*Brassica oleraceae* L. cvar. Gongylodes	Olmia	6/2	C

[1] family [2] cultivar/trade name [3] number of seeds/plants per pot [4] sequence of the tests in 2002/2003 years A/A B/B C/C and D/D **[5]** Maize [6] Apiaceae [7] Liliaceae [8] Brassicaceae [9] form annua

Table 4. Non-Brassicaceous Plants. Average Yield of Vegetables (Plants) [g DM] Average Total Uptake of thallium [µg] by Vegetables from One Pot The Biological Absorption Coefficients (BAC = plant/soil concentration quotient) The Translocation Factor (TLF = Leaves (Straw)/Root (Stalk Seeds) thallium Concentration).

	Maize	Celery		Parsley		Carrot		Onion	
Site[b]	Leaves	Root (celeriac)	Leaves (tops)	Root	Leaves	Root	Leaves	Onion	Tops
Average Yield in One Pot [g DM]									
Nivnice	75.6 (3)	34.8 (12)	26.5 (16)	27.5 (16)	21.8 (10)	27.7 (24)	17.0 (19)	12.7 (26)	2.9 (19)
Heřmanice	63.8 (8)	18.2 (27)	13.8 (16)	22.7 (14)	16.3 (6)	15.3 (15)	8.9 (16)	8.0 (14)	2.3 (12)
Lužice	65.6 (9)	3.8 (42)	4.7 (27)	3.4 (33)	3.8 (28)	5.6 (64)	5.4 (35)	7.0 (24)	1.6 (25)
Average Total Uptake of Thallium from One Pot [µg]									
Nivnice	0.13 (3)	0.37 (20)	0.19 (18)	0.12 (12)	0.14 (28)	0.09 (15)	0.40 (30)	0.02 (21)	0.05 (19)
Heřmanice	0.20 (22)	0.79 (25)	0.24 (31)	0.40 (19)	0.53 (24)	0.18 (19)	0.86 (32)	0.05 (17)	0.09 (15)
Lužice	1.99 (7)	1.21 (41)	0.78 (20)	0.67 (36)	1.41 (37)	1.02 (38)	2.84 (25)	0.91 (32)	1.33 (33)
Average BAC									
Nivnice	0.006 (0.3)	0.036 (22)	0.024 (20)	0.015 (16)	0.021 (20)	0.011 (18)	0.079 (32)	0.006 (22)	0.057 (24)
Heřmanice	0.002 (21)	0.029 (14)	0.011 (22)	0.012 (11)	0.022 (23)	0.008 (16)	0.066 (35)	0.004 (6)	0.027 (11)
Lužice	0.008 (8)	0.098 (17)	0.051 (16)	0.061 (23)	0.111 (22)	0.071 (14)	0.165 (15)	0.040 (16)	0.243 (14)
Average TLF									
Nivnice	_	0.7 (34)		1.5 (29)		7.1 (36)		10.1 (15)	
Heřmanice	_	0.8 (34)		1.8 (19)		8.3 (31)		6.5 (16)	
Lužice	_	0.4 (31)		1.8 (21)		2.3 (16)		6.2 (11)	

[a] RSD [%] is given in parenthesis (n = 6). [b] Nivnice (heavy soil) Heřmanice (medium soil) and Lužice (light soil).

Table 5. Brassicaceous Plants. Average Yield of Vegetables (Plants) [g DM], Average Total Uptake of Thallium [µg] by Vegetables from One Pot, the Biological Absorption Coefficients (BAC = plant/soil concentration quotient), and the Translocation Factor (TLF = Leaves (Straw)/Root (Stalk Seeds) Thallium Concentration).

	kale		spring rape		winter rape *(17)*		kohlrabi	
site[b]	stalk	leaves	seeds	straw	seeds	straw	root	leaves
Average Yield in One Pot [g DM]								
Nivnice	3.3 (21)	14.7 (28)	10.7 (18)	34.7 (11)	7.4 (26)	15.4 (26)	9.4 (49)	20.1 (15)
Heřmanice	1.9 (9)	8.2 (14)	no seed	24.7 (14)	5.7 (23)	13.4 (22)	7.3 (13)	10.9 (16)
Lužice	2.4 (20)	11.7 (7)	2.2 (46)	30.0 (9)	4.2 (16)	14.2 (18)	7.0 (20)	11.8 (6)
Average Total Uptake of Thallium from One Pot [µg]								
Nivnice	0.06(32)	2.23 (26)	1.64 (18)	3.13 (9)	1.21 (37)	2.27 (22)	0.32 (36)	12.0 (17)
Heřmanice	0.05 (16)	2.04 (14)	no seed	9.58 (22)	1.13 (26)	2.45 (15)	0.45 (23)	12.2 (23)
Lužice	0.36 (23)	18.1 (7)	5.50 (35)	42.6 (16)	14.7 (29)	36.1 (18)	4.46 (38)	96.4 (31)
Average BAC								
Nivnice	0.065 (13)	0.515 (13)	0.511 (5)	0.303 (11)	0.539 (23)	0.500 (13)	0.096 (18)	1.94 (8)
Heřmanice	0.017 (18)	0.166 (6)	no seed	0.261 (9)	0.132 (19)	0.124 (13)	0.043 (26)	0.70 (14)
Lužice	0.046 (12)	0.470 (2)	0.804 (21)	0.432 (17)	1.07 (24)	0.743 (24)	0.192 (29)	2.60 (20)
Average TLF								
Nivnice	8 (14)		0.6 (12)		1 (21)		19 (17)	
Heřmanice	10 (17)		No seed		1 (20)		17 (16)	
Lužice	10 (12)		0.5 (11)		0.7 (12)		14 (14)	

[a] RSD [%] is given in parenthesis (n = 6). [b] Nivnice (heavy soil) Heřmanice (medium soil) and Lužice (light soil).

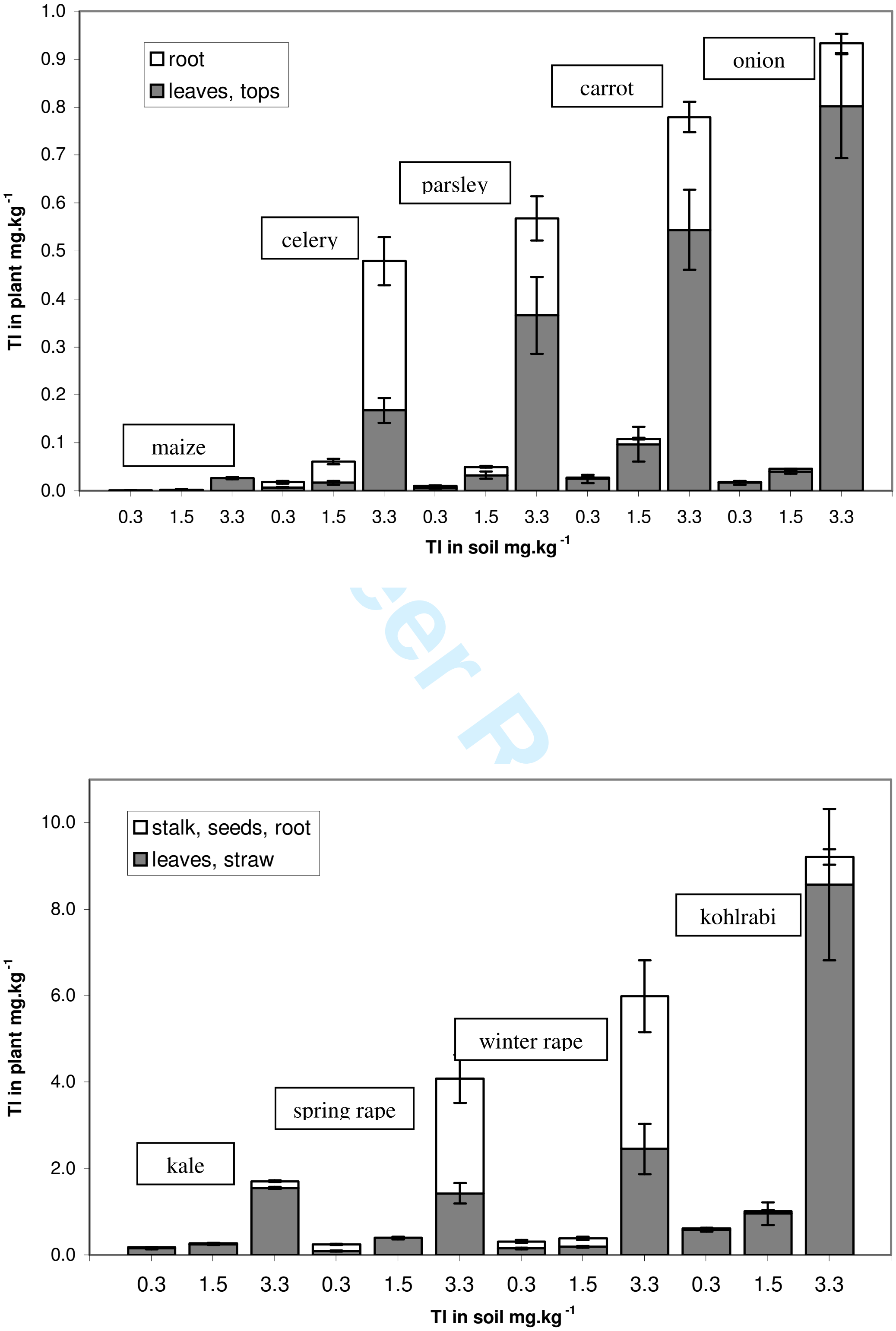

Fig 1. Relationship between the content of thallium [in mg kg^{-1} DM] in the soil and its uptake by separate parts of test plants [in mg kg^{-1} DM] for Brassicaceous plants (bottom) and the other crops (top) respectively.