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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 pedogeochemical 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 (Zbírál et al. 2000; Zbírál 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).

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2
3 68 Anomalous levels of thallium in soils are derived from soil substrate or from an
4 anthropogenic contamination (LaCoste et al. 1991). Ore smelting (Olkusz and Bokowo,
5 69 Poland; Lanmuchang Metallogenic Belt, China), cement production (Lengerich, Germany)
6 70 and combustion of fossil fuels are the main anthropogenic sources of soil contamination
7 71 (Jones et al. 1990; Kemper et al. 1991; Lustigman et al. 2000; Lin et al. 1999a; Lin et al.
8 72 1999b; Sager 1986; Wierzbicka et al. 2004).
9 73
10 74

11 75 Uptake of thallium by different plants was studied mainly on anthropogenically
12 76 contaminated soils or in the field and pot experiments after addition of thallium. It was
13 77 found that plants exhibit species dependent preferences (Xiao et al. 2004) and particularly
14 78 brassicaceous plants can reach very high concentrations of thallium in their tissues without
15 79 any symptoms of phytotoxicity. *Iberis intermedia* Guers. and *Biscutella laevigata* L. can
16 80 have thallium concentration above 1 % dry matter (DM) and can be used for
17 81 phytoremediation or phytomining of thallium (Anderson et al. 1999). Kale (*Brassica*
18 82 *oleracea acephala* L. cv. Winterbor) was found to have behaviour of thallium
19 83 hyperaccumulating plant (Husam et al. 2003). Selection of suitable cultivars with low
20 84 thallium uptake can contribute to reduce the food chain contamination. There were
21 85 observed only small differences between the studied varieties for rape but there were
22 86 differences more than twenty fold for the kale varieties (Kurz et al. 1999). Some authors
23 87 studied equilibrium establishment between plant available and plant non-available
24 88 fractions of thallium in soils (Pavličková et al. 2005). They proved that the equilibrium is
25 89 soil dependent and diffusion driven process. Plants (especially brassicaceous) can
26 90 accumulate much more thallium than determined as a plant available fraction by extraction
27 91 of soil with some weak extractants.
28 92

29 93 LaCoste et al. (LaCoste et al. 1991) tested 11 vegetables in pot trials for two levels of soil
30 94 Tl. 36 crops including 3 wild plants were planted on soils with the thallium content from 1.5
31 95 to 6.9 mg kg⁻¹ (soils were derived from the thallium rich sulphide ores). In both cases
32 96 authors proved very strong species dependent preferences in thallium uptake. Contents up
33 97 to 495 mg kg⁻¹ were found in green cabbage (Xiao et al. 2004). Tremel and Mench (Tremel
34 98 and Mench 1998) recommended monitoring of rape cattle cakes and brassicacea fodders
35 99 for thallium content because their study demonstrated strong possibility of plant
36 100 contamination by thallium of pedogeochemical origin. Rape (*Brassica napus* L.) was tested
37 101 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 (Zbiral et al. 2000; Zbiral 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; anonymous 1998). We can take thallium concentration 0.4 - 2 mg kg⁻¹ DM for fodder crops and 0.25 – 0.5 mg 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; Zbiral et al. 2000; Zbiral 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 °C) using a MA 30 moisture analyser (Sartorius GmbH, Goettingen, 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 TI. 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 (Zbiral et al. 2000; Zbiral et al. 2002; Pavlíčková et al. 2003; Medek et

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2
3 135 al. 2001; Pavlíčková et al. 2005). Operational parameters of the instruments are given in
4
5 136 Table 1.

6
7 137 **Reagents.**

8
9 138 All reagents and standard solutions were prepared using Milli Q deionised water (Millipore,
10 139 Bedford, USA). All chemicals were of reagent grade purity purchased from (Analytika,
11 140 Prague, Czech Republic) and Merck (Darmstadt, Germany). Stock standard solutions
12 141 $1000 \pm 2 \text{ mg L}^{-1}$ Tl in 2% (v/v) nitric acid and $1000 \pm 2 \text{ mg L}^{-1}$ Lu in 2% (v/v) nitric acid
13
14 142 (Analytika, Prague, Czech Republic) were used for preparing of calibrating standard
15
16 143 solutions.

17
18
19 144 **Pot experiments**

20
21 145 *Soils with different pedogeochemical contents of Tl.* Three different soils were collected -
22 146 Nivnice (heavy soil - HS $0.3 \text{ mg Tl kg}^{-1}$ DM), Heřmanice (medium soil - MS $1.5 \text{ mg Tl kg}^{-1}$
23 147 DM) and Lužice (light soil - LS $3.3 \text{ mg Tl kg}^{-1}$ DM). The content of thallium (expressed as
24 148 mg Tl kg^{-1} of dry matter - DM) in all cases was only of pedogeochemical origin. Basic
25
26 149 characteristics of the soils are summarised in Table 2. 7.5 kg of air-dried soil (particles less
27
28 150 than 2 cm) were used for filling a pot. Six replicates for each soil and each plant (90 pots
29
30 151 for the experiment) were used. Five crops - spring rape, winter rape, kale, kohlrabi and
31
32 152 maize were tested in the first year and celery, parsley, carrot, and onion were tested in the
33
34 153 same pots next year (for the scheme of the experiment see Table 3). Winter rape was
35
36 154 sowed in each pot in August. Normally developed plants were singled out in September.
37
38 155 Other crops were sowed in April and singled out in May. The fully matured plants were
39
40 156 harvested in July. The soils were fertilized with N (NH_4NO_3), P ($\text{CaHPO}_4 \cdot 2 \text{ H}_2\text{O}$) and K
41
42 157 (KCl) according to the individual demands of each crop to provide a sufficient nutrient
43
44 158 supply. The pots were protected against rain during the whole period. Soil moisture was
45
46 159 adjusted to 60% of maximum water capacity by daily watering with deionized water. During
47
48 160 the harvest the plant parts were collected separately weighed and stored for analysis.

49 161 **Sample preparation and digestion.**

50
51 162 Plant samples were mechanically cleaned immediately after the harvest and subsequently
52
53 163 by a quick washing with deionised water to remove the rest of soil and dust particles. Plant
54
55 164 samples were dried and finely ground. The rapeseeds were analysed without grinding. The
56
57 165 all samples (1 g) were digested by nitric acid (8 ml HNO_3 and 10 ml H_2O) in the microwave
58
59 166 digestion system at $145 \text{ }^\circ\text{C}$ and 700 W for 5 min $180 \text{ }^\circ\text{C}$ and 600 W for another 5 min and
60 167 finally at $180 \text{ }^\circ\text{C}$ and 1000 W for the next 5 min. The digests were adjusted to the final
168 volume of 50 ml with deionized water. The digests were further diluted 1-20 times by

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2
3 169 deionized water before the ICP/MS measurement. Each series consisted of a suitable
4 amount of samples given by the procedure one internal reference standard and two
5 170
6 blanks.
7 171

8
9 172 Soil samples were air-dried gently crushed and sieved. Fraction < 2 mm according
10 to ISO 11464 was used for the analysis. Soils were digested (Pavličková et al. 2003) by
11 173
12 HNO₃-H₂O₂ (2 g soil sample 10 ml HNO₃ and 20 ml H₂O₂ were used boiling for four hours
13 174
14 under cooler). Soil extracts were diluted 5 - 10 times by deionized water before the
15 ICP/MS determination. Each series consisted of a suitable number of samples given by
16 176
17 the procedure two internal reference standards and two blanks.
18 177

19 178 ***Determination of thallium by ICP/MS.***

20
21 179 Single element calibrating standard solutions were used for calibration of the ICP/MS
22 instrument at five different concentrations of thallium (0, 1, 5, 10 and 50 µg L⁻¹). Lutetium
23 180
24 at the concentration 10 µg L⁻¹ was used as an internal standard (¹⁷⁵Lu signals). The
25 181
26 extraction agents acids and lutetium concentrations in the standard calibrating solutions
27 182
28 matched their concentrations in the sample solutions. The calibration curve was linear in
29 183
30 the whole calibrating range (r = 0.9999). Limit of detection 1.2 µg kg⁻¹ was achieved for the
31 184
32 samples (3 S/N criterion). Thallium content was determined from ²⁰⁵Tl signal.
33 185
34 186

35 187 **RESULTS AND DISCUSSION**

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37 188
38
39 189 The results of the pot experiments are given in Tables 4 and 5 for Brassicaceous plants
40 and the other crops respectively. The contents of thallium in different parts of the crops for
41 190
42 all three investigated soils are given in Figure 1. Average total uptake of thallium from the
43 experimental pot did not follow exactly the concentration of thallium in soil. Uptake of
44 192
45 thallium from the light soil (Lužice) with the highest content of thallium (3.3 mg kg⁻¹) was
46 193
47 ten times higher than from both other soils.
48 194
49 195

50
51 196 The bioaccumulating factor - BAF (concentration of thallium in plant (or its
52 part)/concentration of thallium in soil) reflects thallium availability from the given soil. The
53 197
54 highest bioaccumulating factors were found for the light soil (Lužice) and than for the
55 198
56 heavy soil (Nivnice). Thallium in medium soil (Heřmanice) in spite of its relatively high level
57 199
58 (1.5 mg kg⁻¹) was found to be less available. BAFs for non-brassicaceous plants were
59 200
60 usually below 0.1 even for the soil from Lužice. Higher BAFs for these plants were
201
202 observed for green parts of vegetables (onion, carrot, parsley) than for other parts. Celery

1
2
3 203 was the only exception of this rule. The situation was substantially different for plants of
4
5 204 the Brassicaceae family. BAFs for spring and winter rape were near 1 as found also in the
6
7 205 previous studies focused on this crop (Zbiral et al. 2000; Zbiral et al. 2002; Pavlíčková et
8
9 206 al. 2003; Medek et al. 2001; Pavlíčková et al. 2005). BAFs higher than 0.4 were found for
10
11 207 the other tested brassicaceous plants (except for stalk of kale and kohlrabi). BAF 2.6 was
12 208 observed as high as for the green part of kohlrabi.
13

14 209
15
16 210 The translocation factor – TLF (the ratio of thallium concentration in different parts of the
17
18 211 plant) shows that for most crops (brassicaceous and others) higher thallium concentration
19 212 is located in the green part of the plant. The highest TLF was found for kohlrabi (19), kale
20
21 213 (10), but also for onion (10) and carrot (8). Concentration of thallium in celeriac part of
22
23 214 celery was found to be higher than in the green part.
24

25 215
26 216 If we take thallium concentration $0.4 - 2 \text{ mg kg}^{-1}$ DM for fodder crops and $0.25 - 0.5 \text{ kg}^{-1}$
27
28 217 DM for food as a provisional working limit and adopt 0.25 and 0.4 mg kg^{-1} for the
29
30 218 evaluation (anonymous 1997; anonymous 1998) it can be concluded that for heavy soils
31
32 219 from Nivnice, and (a bit surprisingly) medium soils (Heřmanice) most crops and their parts
33
34 220 were below the limit. Straw of spring rape was above the limit and leaves of kale just on
35 221 the limit for food on medium soil (Heřmanice). The green part of kohlrabi was able to
36
37 222 accumulate thallium even from soil with only a background content of thallium and this part
38
39 223 of plant proved to be unsuitable for food or feed for all investigated soils. Brassicaceous
40
41 224 plants grown on light soil (Lužice) substantially exceeded the limits with only one exception
42 225 – stalk of kale. Non-brassicaceous crops showed also relatively high concentration of
43
44 226 thallium on light soil (Lužice). The celeriac part of celery and the green part of parsley
45
46 227 exceeded the limit for food and the green parts of carrot and onion exceeded the limit for
47
48 228 feed.
49

50 229 51 230 **CONCLUSIONS**

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53 231
54
55 232 The total content of thallium in soil, physico-chemical form and form of binding to soil
56
57 233 particles seem to be the main factors influencing the uptake by a plant. From the data
58 234 presented hereby it can be seen that thallium is an exception since the values obtained for
59
60 235 other elements in all vegetables are significant smaller than the corresponding plant-soil
236
concentration ratios for the uncontaminated soil. These results demonstrate quantitatively

1
2
3 237 that the ability of a plant to accumulate a metal compared to a control soil might not exist
4
5 238 for an anthropogenically contaminated soils and vice-versa. In addition thallium can be
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7 239 present as Tl(I) or Tl(III) which makes it necessary to distinguish between these two
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9 240 species (Lin et al. 1999a; Lin et al. 1999b). Without this specification a correct toxicological
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11 241 evaluation is not possible particularly since Tl(I) possibly occurs in soluble whereas T(III) in
12
13 242 colloidal form.

14 243
15
16 244 Uptake of thallium by plants is species dependent. Plant varieties and plant parts differ in
17
18 245 the degree of uptake and accumulation of Tl. Some brassicaceous plants commonly grown
19
20 246 as vegetables behave as hyperaccumulators of Tl. Content of thallium in different aerial
21
22 247 parts of tested plants can differ substantially (nearly 20 times in maximum). The highest
23
24 248 concentration was observed mainly in the green parts of the particular plants. Green part
25
26 249 of kohlrabi can contain thallium in concentration exceeding the provisional limit even if
27
28 250 grown on soil with very low natural content of Tl.

29 251
30 252 The concentration of thallium in vegetables in many cases can substantially exceed the
31
32 253 concentration of thallium in soils. Thus thallium content should be monitored and the plants
33
34 254 with high thallium accumulation power should be excluded from growing for human or
35
36 255 animal nutrition in contaminated areas. The above mentioned facts are often neglected
37
38 256 because legal measures are usually taken only for the areas anthropogenically
39
40 257 contaminated as a result of a human activity. Uptake of thallium from soils with naturally
41
42 258 high content of thallium can be high enough to seriously endanger food chains (directly by
43
44 259 consumption of plants grown on contaminated soils indirectly by consumption of meat from
45
46 260 animals feed by rape cattle cakes a by-product of rapeseed oil production).

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6 380 Fig. 1. Relationship between content of thallium [in mg kg⁻¹ DM] in the soil and its uptake
7 381 by separate parts of the test plants [in mg kg⁻¹ DM] for Brassicaceous family (bottom) and
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9 382 the other crops (top) respectively.
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386 Table 1. Operational parameters of Elan 6000 ICP-MS

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 H₂O₂ - HNO₃ 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	<i>Zea mays</i> L.	Cemilk H285	12/4	A
Celery ⁶	<i>Apium graveolens</i> var. Rapaceum	Maxim	-/2	A
Parsley ⁶	<i>Petroselinum crispum</i> cvar. Erfurtense	Dobra	20/8	B
Carrot ⁶	<i>Daucus carota</i> L.	Berjo	20/8	C
Onion ⁷	<i>Allium cepa</i> L.	Všetana	-/6	D
Spring rape ⁸	<i>Brassica napus</i> L. cvar. <i>Napus</i> ⁹	Golda	20/10	E
Winter rape ⁸	<i>Brassica napus</i> L. cvar. <i>Napus</i>	Zoro	20/10	D
Kale ⁸	<i>Brassica oleracea</i> L. var. <i>Acephala</i>	Winterbor F1	6/2	B
Kohlrabi ⁸	<i>Brassica oleracea</i> L. cvar. <i>Gongylodes</i>	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).

site ^b	kale		spring rape		winter rape (17)		kohlrabi	
	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)	

^aRSD [%] is given in parenthesis (n = 6). ^bNivnice (heavy soil) Heřmanice (medium soil) and Lužice (light soil).

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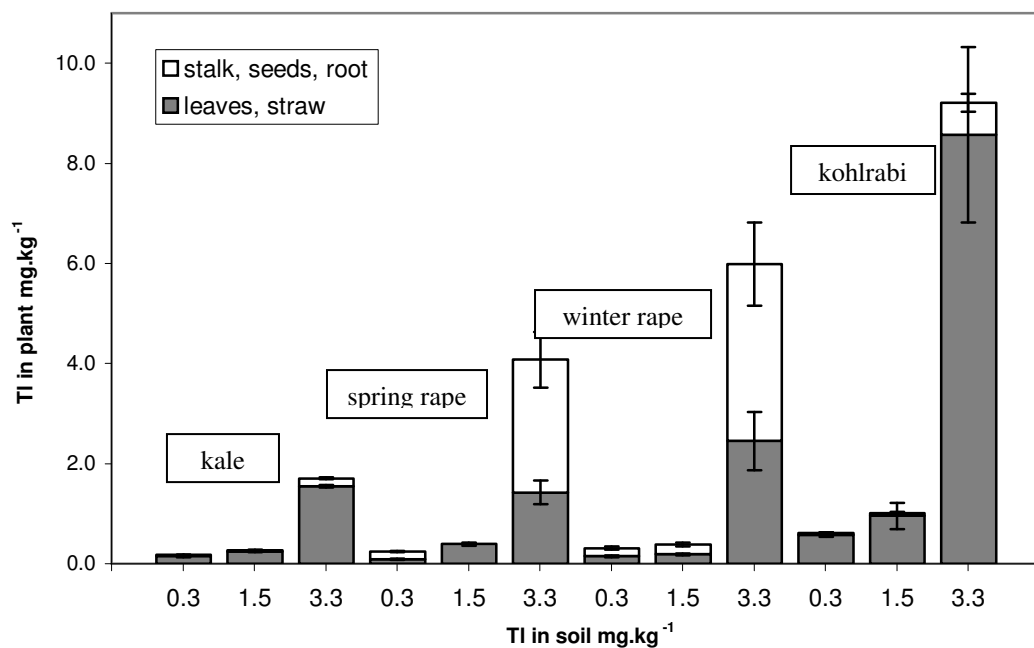
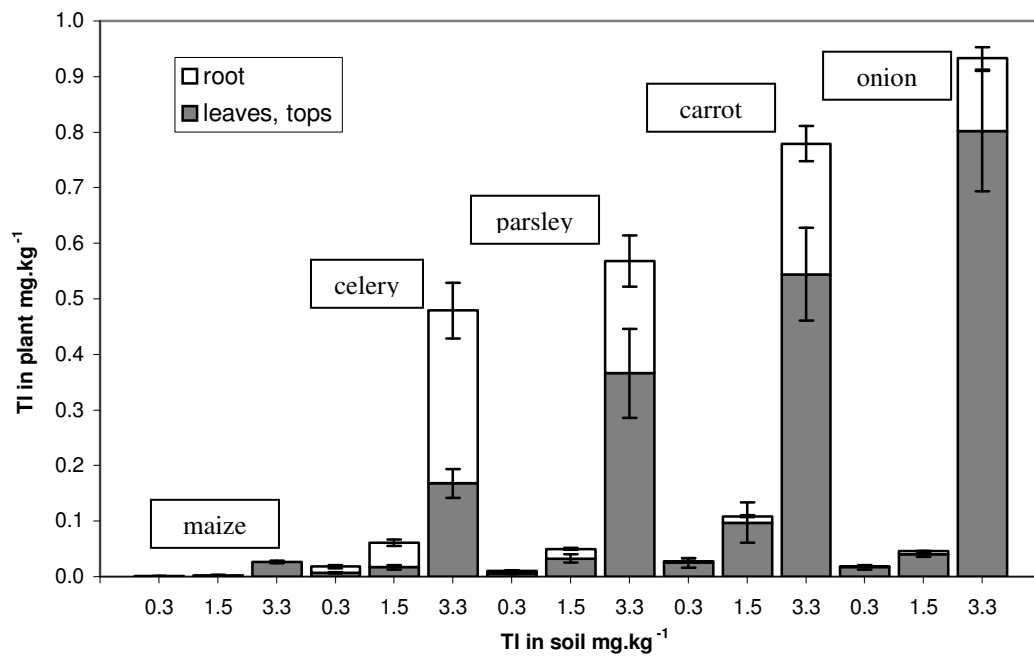


Fig 1. Relationship between the content of thallium [in mg kg⁻¹ DM] in the soil and its uptake by separate parts of test plants [in mg kg⁻¹ DM] for Brassicaceous plants (bottom) and the other crops (top) respectively.