JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

J. Agric. Food Chem. **2005,** *53,* 2867−2871 **2867**

Uptake of Thallium from Artificially and Naturally Contaminated Soils into Rape (*Brassica napus* L.)

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An inductively coupled plasma mass spectrometry (ICP/MS) method was used for the evaluation of thallium transfer from naturally (pedogeochemically) and artificially contaminated soils into rape. Two sets of three different types of top soils (heavy, medium, and light) were used for pot experiments. The first set was collected from areas with high levels of pedogeochemical thallium (0.3, 1.5, and 3.3 mg kg^{-1} DM). The second set of three soils with naturally low content of thallium was artificially contaminated with thallium sulfate to achieve five levels of contamination (0, 0.4, 2, 4, and 6 mg kg^{-1} DM Tl). The soil samples and the samples of winter and spring rape (straw, seeds) from both sets were collected and analyzed. Plant and soil samples from fields were collected at 42 selected sites situated in South Bohemia and in Czech-Moravian Highlands where higher pedogeochemical content of thallium was expected. More intensive transport (better availability) of Tl was observed in the case of artificially contaminated soils. The physicochemical form and the total content of Tl in soil were found to be the main factors influencing its uptake by plants. The concentration of Tl in rapeseeds in the field samplings was mostly 45% of its content in the particular soil. Nevertheless the uptake of Tl from soils with naturally high pedogeochemical content can be high enough to seriously endanger food chains. These findings are very important because of the high toxicity of Tl and the absence of threshold limits for Tl in soils, agricultural products, feedstuffs, and foodstuffs in most countries including the Czech Republic.

KEYWORDS: Thallium; uptake; contamination; oilseed; rape; pot tests; field tests

INTRODUCTION

Thallium is a rare and dispersed element that occurs mainly in sulfur-containing ores and potassium minerals (*1*−*4*). The highest Tl contents were found in soils derived from acid or neutral rocks (granite, syenite, granodiorite). Occasionally, slightly elevated contents were found on metamorphous rocks (granulite, meta-granite), and the lowest levels were found in soil on neogene rocks (basal conglomerates and sandstones) and quaternary rocks (alluvial sediments, gravel, sand, loam).

Both mono- and trivalent thallium and their compounds are nonessential, and they are toxic (*1*−*3*) to all organisms (plants, animals, humans). Toxicity of thallium (Tl) can be compared with the toxicity of lead and mercury (*1*). As far as relatively high contents of Tl in soils (*4*, *5*), a potential risk for humans can arise at levels around 1 mg kg^{-1}. Especially growing of *Brassicaceae* crops can pose a risk for the food chains because of elevated accumulation of Tl in plant tissues (*1*, *2*).

Thallium was found to be relatively mobile in soils (*6*). The phytoavailability of the element depends on plant species (*2*, *7*, *8*). Winter rape (*Brassica napus* L.) and to a lesser extent turnip and garden cabbage accumulated Tl into the aerial parts (up to 20 mg kg^{-1} of dry weight). For the other plant species (carrot, French bean, potato, winter wheat), the amount of Tl taken up is lower and Tl is accumulated in roots. Relatively high Tl concentrations (up to 33 mg kg^{-1} of dry weight) were found in rape shoots and seeds (*4*). The Tl content prompts questions on the potential of pedogeochemical Tl for food chain contamination. Cabbage, turnip, and cattle rape expellers could be placed under control since high correlation coefficients between Tl content in soil and plants ($r > 0.6$) have been found.

The normal human daily intake, mainly by food, is estimated to be about 2 μg in nonpolluted areas (*8*). In cattle from polluted regions, the highest levels were found in kidney, liver, muscle tissue, and endocrine gland. Because of similar ionic radii of Tl^{+} and K^{+}, Tl^{+} is transported in the same way as potassium and accumulates mainly intracellularly. Another mechanism of

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10.1021/jf048042k CCC: $30.25
Published on Web 03/24/2005

Table 1. Basic Characteristics of Topsoils[a] Used for Pot Experiments (All Data Given for DM)

parameter	unit	Hrubčice	Míchov	Račín	Nivnice	Heřmanice	Lužice
Tl[b]	mg kg^{-1}	0.5	0.3	0.4	0.3	1.5	3.3
pH/$CaCl_2$		7.0	6.3	5.0	6.9	6.1	6.4
P[c]	mg kg^{-1}	138	178	58	105	310	62
K[c]	mg kg^{-1}	301	459	253	798	702	174
Mg[c]	mg kg^{-1}	463	233	49	281	152	636
Ca[c]	mg kg^{-1}	7090	3230	723	4730	2260	2520
fraction < 10 μm	%	63.7	37.9	28.1	54.3	22.1	17
fraction < 1 μm	%	38.4	17.2	9.6	32.5	7.2	5.2
fraction 1–10 μm	%	25.3	20.7	18.5	21.8	14.9	11.8
fraction 10–50 μm	%	28.5	40.1	26.5	20.8	16.9	16.3
fraction 50–250 μm	%	6.7	19.2	19.7	17.7	18.9	27.4
fraction 0.25–2 mm	%	1.1	2.8	25.7	7.2	42.1	39.3
N(t)	%	0.22	0.14	0.09	0.25	0.18	0.17
Cox	%	2.35	1.32	1.07	1.79	2.29	1.72
CEC	mM kg^{-1}	430	270	150	410	405	368

[a] Hrubčice (heavy soil), Míchov (medium soil), and Račín (medium to light soil); 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.

Tl toxicity seems to be analogous to the enzyme inhibition by Pb and Hg resulting in a general toxicity. Central nervous system is the main target organ in Tl human intoxication. Some studies demonstrated mutagenic properties, increased frequency of DNA breaks, damages of reproduction systems of animals and humans, and teratogenicity for chick embryo.

Reported values of Tl in human body fluids and tissues are contradictory. Threshold limits are important in the fields of occupational and veterinary medicine and environmental control to prevent health risks. Maximum Tl content in food (0.1 mg kg^{-1} of fresh weight) has been established in Germany, and an actual daily intake value of 5 μg per day was published in the U.S.A. (*9*).

For contents of Tl less than 1 mg kg^{-1} in *aqua regia* soil extracts, the contents of this element in rape seeds were usually below 0.3 mg kg^{-1}. Higher contents of *aqua regia* extractable Tl were found in soils derived from melanocratic granite, granite, and quartzite monzonite. Concentration of Tl in rape seeds was only about 10% for quartzite monzonite, about 50% for granite, and more than 100% for melanocratic granite in comparison to the content of this element in *aqua regia* soil extracts.

Several analytical procedures can be used for the determination of thallium (*10*). Flame atomic absorption spectrometry and inductively coupled plasma emission spectrometry are not very sensitive for determination without preconcentration (*11*). Electrothermal atomic absorption spectrometry is more sensitive, but Zeeman background correction and stabilized temperature platform furnace have to be used (*4*, *12*, *13*). Extraction spectrophotometric determination of thallium in soils was also applied (*14*, *15*). Inductively coupled plasma mass spectrometry (ICP/MS) was found to be a very suitable method for the determination of thallium (*16*−*22*). Both thallium isotopes, ^{203}Tl and ^{205}Tl, can be used for the determination.

Several soil extraction procedures suitable for the determination of thallium were studied (*18*−*20*). Digestion by nitric acid and hydrogen peroxide proved to be the most suitable. *Aqua regia* soil extracts have been used for the determination of many potentially dangerous elements in soils, and the extraction procedure has been internationally accepted (*19*−*21*).

The main goal of the present work is to elaborate a suitable method for the evaluation of thallium uptake from naturally (pedogeochemically) contaminated soils and soils with artificially elevated Tl concentrations into rape. Field and pot experiments were conducted to compare Tl contents in top soils and in straw and seeds of different varieties of rape.

MATERIALS AND METHODS

Instruments. Plant samples (straw, seeds) were finely ground using a high-speed mill Grindomix (Retsch, Germany) and digested by nitric acid in a closed high-pressure microwave system (Ethos SEL, Milestone, Italy). Dry matter was determined (2 g of a sample, 105 °C) using a MA 30 moisture analyzer (Sartorius GmbH, Goetingen, Germany). A 16-position double heating block with digestion tubes and coolers, MB 422 BH (Uni Elektro, Hradec Králové, Czech Republic), was applied for soil digestion. A subboiling 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) 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 controlled by a calibrating solution (Perkin-Elmer SCIEX, Norwalk). The operating parameters were identical with those given in the previous papers (*18*, *20*−*22*).

Reagents. All reagents and standard solutions were prepared using Milli Q deionized water (Millipore, Bedford, MA). All chemicals of reagent grade purity were from Analytika, (Prague, Czech Republic), Merck (Merck KGaG, Darmstadt, Germany), or Pliva-Lachema (Pliva-Lachema Comp., Brno, Czech Republic). 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, were used for preparation of calibrating standard solutions. Thallium sulfate solutions (0.1, 0.5, 1.0, and 1.4 g L^{-1} Tl) were used for artificial contamination of soils in pot experiments.

Pot Experiments. *Contaminated Soils.* Three different types of topsoil were collected, Hrubčice (heavy soil, HS), Míchov (medium soil, MS) and Račín (medium to light soil, MLS), and characterized according to the Novák's scale (*23*) based on the relative content of the finest clay particles (<2 μm) in dry sieved matter (particles < 2 mm). Basic parameters of the soils are summarized in Table 1. The soils were dried at laboratory temperature (DM) and sieved, and all particles < 2 cm were homogenized and used for the pot experiments in a vegetation hall. All soils were fortified with thallium sulfate solution (0.1, 0.5, 1.0, and 1.4 g L^{-1} Tl; 50 mL per 12 kg of soil) to achieve five levels of added thallium content (0, 0.42, 2.1, 4.2, and 5.8 mg kg^{-1} DM). Kale (*Brassica oleracea* L., var. *Acephala*, cultivar Winterbor) was planted in the pots during the first year after the contamination. The content of the pot was carefully cleaned and homogenized after the harvest and reused for the next experiments. Six replicates were used for each soil and each level of contamination (9 kg of soil per pot, 90 pots in the experiment). Natural content of Tl in the soils was 0.5 mg kg^{-1} DM (Hrubčice, HS), 0.3 mg kg^{-1} DM (Míchov, MS), and 0.4 mg kg^{-1} DM (Račín, MLS).

The soils were fertilized with 83 mg kg^{-1} N (NH_4NO_3), 25 mg kg^{-1} P ($CaHPO_4 \cdot 2H_2O$), and 56 mg kg^{-1} K (KCl) to provide a sufficient nutrient supply. Exactly 21 seeds of spring rape (*Brassica napus* L.,

Table 2. Average Yield of Spring Rape (Seeds and Straw; g DM), Average Content of Thallium in Spring Rape (mg kg^{-1} DM), and Average Absolute Uptake of Thallium (μg) by Spring Rape in a Single Pot[a]

site[b]	parameter	Tl added (in mg kg^{-1} DM) 0	0.5	2	4	6
		Seeds				
Hrubčice	yield	7.9 (13)	7.6 (10)	7.8 (5)	7.4 (29)	8.2 (9)
	content	0.04 (23)	1.14 (12)	6.26 (27)	16.13 (20)	21.42 (10)
	uptake	0.31 (28)	8.70 (18)	48.36 (24)	115.2 (27)	175.2 (10)
Míchov	yield	5.6 (38)	7.5 (10)	8.5 (9)	7.5 (14)	6.3 (13)
	content	0.10 (24)	3.47 (18)	24.78 (16)	50.72 (22)	82.00 (12)
	uptake	0.54 (42)	25.9 (21)	210.8 (18)	389.2 (34)	513.6 (15)
Račín	yield	4.4 (25)	3.9 (25)	3.7 (21)	4.6 (23)	2.6 (39)
	content	0.14 (25)	1.99 (20)	6.91 (27)	24.37 (48)	35.45 (30)
	uptake	0.65 (42)	7.58 (21)	25.11 (27)	114.7 (54)	95.33 (54)
		Straw				
Hrubčice	yield	36.8 (11)	41.5(12)	40.5 (8)	37.6 (13)	38.7 (11)
	content	0.04 (43)	0.62 (10)	3.21 (20)	8.56 (27)	12.41 (13)
	uptake	1.32 (48)	26.00(17)	129.9 (22)	316.3 (21)	481.4 (17)
Míchov	yield	46.8 (11)	45.2 (18)	45.9 (9)	44.1 (14)	42.4 (8)
	content	0.05 (23)	1.67 (25)	9.48 (19)	23.20 (22)	39.03 (11)
	uptake	2.35 (31)	77.16(39)	430.8 (15)	1004.3 (16)	1660 (16)
Račín	yield	26.2 (17)	24.6 (14)	25.1 (15)	25.8 (11)	25.4 (13)
	content	0.10 (19)	1.31 (33)	3.80 (32)	14.21 (30)	21.27 (22)
	uptake	2.59 (22)	31.45(27)	92.20 (27)	365.5 (33)	534.2 (19)

[a] RSD [%] is given in parentheses. [b] Hrubčice (heavy soil), Míchov (medium soil), and Račín (medium to light soil).

convar. *Napus*, form annua, cultivar Golda) were sowed in each pot in April. Normally developed plants were singled out in May. Thus only eight of the best-developed plants remained in one pot. 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. The harvest of fully matured plants was in July, and seeds and straw were collected separately, weighed, and stored for analyses.

Soils with High Pedogeochemical Content of Tl. Three different types pedogeochemically contaminated topsoil were collected, Nivnice (heavy soil, HS, 0.3 mg of Tl kg^{-1} DM), Heřmanice (medium soil, MS, 1.5 mg of Tl kg^{-1} DM), and Lužice (light soil, LS, 3.3 mg of Tl kg^{-1} DM). Basic characteristics of the soils are summarized in Table 1. Exactly 7.5 kg of air-dried soil (particles less than 2 cm) were used for filling a pot in six replicates for each soil and each rape variety (36 pots for the experiment). Two crops, spring rape (*Brassica napus* L., convar. *Napus*, form annua, cultivar Golda) and winter rape (*Brassica napus* L., convar. *Napus*, cultivar Zoro), were tested. In these experiments, 20 seeds of spring rape were sowed in each pot in April. The plants were singled out in May; 10 fully developed plants remained in one pot. The soils were fertilized with 83 mg kg^{-1} N (NH_4NO_3), 25 mg kg^{-1} P ($CaHPO_4{\cdot}2H_2O$), and 56 mg kg^{-1} K (KCl) to provide a sufficient nutrient supply. The fully matured plants were harvested in July.

Exactly 20 seeds of winter rape (*Brassica napus* L., convar. *Napus*, cultivar Zoro) were sowed in each pot in August. Normally developed plants were singled out in September; 10 well-developed plants remained in one pot. The soils were fertilized with 100 mg kg^{-1} N (NH_4NO_3), 37 mg kg^{-1} P ($CaHPO_4{\cdot}2H_2O$), and 83 mg kg^{-1} K (KCl). The fully matured plants were harvested in July. All the other conditions (soil homogenization, water regime, harvest, etc.) were the same as those described for the pot experiments on artificially contaminated soils.

Field Sampling−Areas with High Pedogeochemical Content of Tl. Sampling sites (42 sites) were selected according to the previous survey (*17*, *19*−*21*) in South Bohemia and in Czech-Moravian Highlands using a geological map of the Czech Republic, 1:50 000. Sites suspected for a higher pedogeochemical content of thallium in soils were selected. Soil samples were collected from the topsoil layer (usually 0−20 cm) by Edelman hand auger set for heterogeneous soils (Eijkelkamp, Giesbeek, The Netherlands). The composite soil sample (500 g minimum sample weight) was bulked from 7−10 single samples. An average sample of rape seeds was taken from each plot (200 g minimum sample weight).

Sample Preparation and Digestion. Plant samples were cleaned immediately after the harvest by a quick washing with deionized water to remove dust particles. Straw samples were dried at laboratory temperature and finely ground. The seeds were used without grinding. The samples (1 g) were digested in nitric acid (8 mL of HNO_3 and 10 mL of H_2O) in the microwave digestion system at 145 °C and 700 W for 5 min, 180 °C and 600 W for another 5 min, and finally 180 °C 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 1−100 times by deionized water before the ICP/MS measurement of thallium content. 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. A fraction of <2 mm according to ISO11464 was used for the analysis. Soils were digested (*20*) by HNO_3−H_2O_2 (2 g of soil sample, 10 mL of HNO_3, and 20 mL of H_2O_2 were used and boiled for 4 h under cooler). Soil extracts were diluted 5−10 times by deionized water before the ICP/MS determination of thallium content. 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 four different concentrations of Tl (0, 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 ($r \geq 0.9999$). Thallium content was determined from ^{205}Tl signal. EXCEL97 (Microsoft, Redmont, WA) software was used for statistical evaluation of the data by the regression analysis.

RESULTS AND DISCUSSION

Pot Experiments. Addition of thallium to the soils nonsignificantly influenced the yield of rape (see Table 2) except in the experiments with the highest Tl addition in the poorest medium to light soil (Račín, MLS). Approximately 40% depression of the yield of seeds (compared to the zero addition) and the highest variation between the replicates was observed for this soil at this level of contamination.

From Table 2, it can be concluded that the contents of thallium, as well as the uptake of this element by the tested

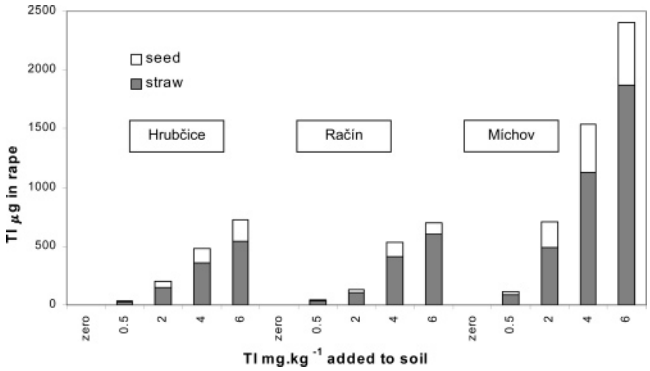

Figure 1. Absolute uptake of Tl (in mg kg^{-1} DM) by spring rape. For conditions, see text.

Table 3. Average Yield of Spring and Winter Rape (Seeds, Straw; g DM), Average Content of Thallium (mg kg^{-1} DM), and Average Total Uptake of Thallium (µg) by Spring and Winter Rape from One Pot with Pedogeochemically Contaminated Soils

	spring rape		winter rape	
site[b]	seeds	straw	seeds	straw
	Average Yield in One Pot			
Nivnice	10.7 (18)	34.7 (11)	7.4 (26)	15.4 (26)
Heřmanice	no seed	24.7 (14)	5.7 (23)	13.4 (22)
Lužice	2.2 (46)	30.0 (9)	4.2 (16)	14.2 (18)
	Average Content of Thallium			
Nivnice	0.15 (5)	0.09 (11)	0.16 (23)	0.15 (13)
Heřmanice	no seed	0.39 (9)	0.20 (19)	0.19 (13)
Lužice	2.65 (35)	1.42 (17)	3.53 (24)	2.45 (24)
	Average Total Uptake of Thallium from One Pot			
Nivnice	1.64 (18)	3.13 (9)	1.21 (37)	2.27 (22)
Heřmanice	no seed	9.58 (22)	1.13 (26)	2.45 (15)
Lužice	5.50 (35)	42.56 (16)	14.72 (29)	36.13 (18)

[a] RSD [%] is given in parentheses. [b] Nivnice (heavy soil), Heřmanice (medium soil), and Lužice (light soil).

plants from one pot, were higher for higher additions of thallium. Lower uptake for the highest addition on MLS soil (Račín, see Table 2) is a result of the yield depression. The contents of thallium in seeds were found in the range 1.1−3.5 mg kg^{-1} DM even for the lowest level of contamination. On the other hand, the highest content of thallium (82 mg kg^{-1} DM) was determined in seeds planted on the soils with the highest Tl addition (6 mg kg^{-1} DM). Thus the concentration of thallium in seeds was nearly 14 times higher compared to its concentration in soil. The content of thallium in seeds was found to be 1.5 to 2.6 times higher than that in straw. The highest ratio of the content of thallium in seeds and straw was found for medium soils (MS) from site Míchov and the lowest for medium to light soils (MLS) from site Račín. The total uptake and the distribution of Tl between seeds and straw are summarized in Figure 1. Maximum absolute uptake of thallium (2.2 mg per pot) from one experimental pot was observed for medium soils (MS) from site Míchov. It was about 4% of the total content of this element in the pot.

The yields of rape planted in pots with the soils with high pedogeochemical content of thallium are summarized in Table 3. No seed developed on the medium soil Heřmanice (MS) for spring rape. The contents of thallium in seeds and straw for both rape varieties (spring, winter) and absolute uptakes of thallium are summarized in Table 3. As can be seen, the Tl accumulation is really high compared with the threshold values (20 mg kg^{-1} DM) considered excessive or toxic for mature leaf tissues (*24*).

Table 4. Field Experiments–Descriptive Statistics of the Contents of Tl in Soils and Winter Rape Seeds (mg kg^{-1} DM)

N = 42	mean	median	minimum	maximum	LQ[a]	UQ[b]
soils	2.02	2.01	0.46	3.93	1.65	2.55
seeds	1.05	1.00	0.12	3.93	0.49	1.42

[a] Lower quartile [b] Upper quartile.

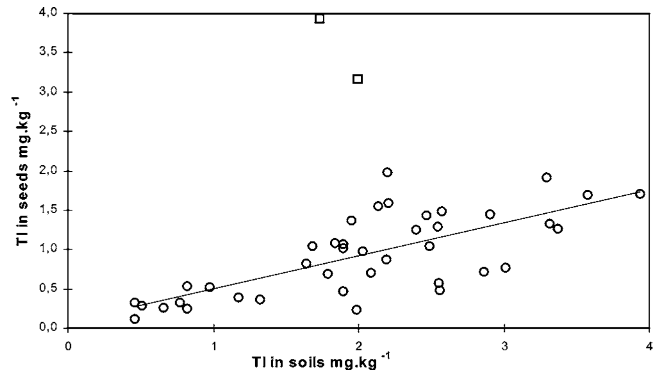

Figure 2. Relationship between the content of Tl (in mg kg^{-1} DM) in soils and seeds (in mg kg^{-1} DM) of rape (field sampling). $Y = 0.4206x + 0.0763$; $R^2 = 0.53$. For conditions, see text.

Very low uptake of Tl was observed for the heavy soils (HS) from site Nivnice (relatively low content of Tl 0.3 mg kg^{-1} DM). Practically the same very low uptakes were found for winter rape planted on the medium soils (MS) from site Heřmanice with much higher content of Tl (1.5 mg kg^{-1} DM). The light soils from site Lužice (LS, 3.3 mg kg^{-1} DM) gave substantially higher contents of Tl in spring and winter rape. The higher bioaccumulation of Tl into seeds than into straw (ratio 1.9) was observed in spring variety. The ratio of 1.47 and the concentration of Tl of 3.53 mg kg^{-1} DM in seeds were determined for winter variety. It can be concluded that also naturally high contents of Tl in soil can have a serious impact on the food chain. Absolute uptake of thallium from one experimental pot for Lužice light soil (LS) for spring and winter variety was 48 or 51 µg, respectively (about 0.2% of the total content of this element in the pot).

Field Sampling. Most soil and plant samples (*17*, *19*−*21*) were taken from sites of the Třebíč pluton (southern part of the Czech-Moravian Highlands) where soil substrate is based on granites and quarz-syenites. Several soil and plant samples (*17*, *19*−*21*) were taken from sites located in South Bohemia (Písek pluton). The results of analyses and those of descriptive statistics of the data are given in Table 4 and regression analysis in Figure 2. Two outliers were excluded from the regression analyses (top of the figure).

From the results of descriptive statistics and regression analysis can be concluded that the content of Tl in rape seeds in these regions is approximately 45% of its content in the soil (determined under given conditions). From the coefficient of determination (R^2), it is clear that only 53% of cases can be explained by the regression equation even if two outliers were not taken into the evaluation ($Y = 0.4206x + 0.0763$; $R^2 = 0.53$). It can be explained by the fact that there are further factors influencing the uptake of Tl than only its content in a particular soil (soil composition, physicochemical status of Tl, etc.). Unfortunately, there were too few samples from the areas with other soil substrates to allow statistical evaluation according to these substrates. The variety of the rape plays also an important role in the uptake of thallium. The information about the varieties were not available for the evaluation and will be taken in consideration in future experiments. Nevertheless the content of Tl in soils seems to be the most important factor for its uptake.

Conclusions. Higher transfer of Tl was observed in the case of artificially contaminated soils. Tl in these soils was more bioavailable even 1 year after the contamination if compared to the soils with naturally high content of this element. The physicochemical form, form of binding, and total content of Tl in soil seem to be the main factors influencing the uptake by plants.

Rape varieties and plant parts differ in the degree of uptake and accumulation of Tl. Uptake of Tl from soils with a naturally high content of Tl can be high enough to seriously endanger food chains (directly by consummation of plants grown on contaminated soils, indirectly by consummation of meat from animals fed by rape cattle cakes, a byproduct of rapeseed oil production). This fact is often neglected because legal measures are usually taken only for the areas contaminated as a result of a human activity.

The main factor influencing the uptake of Tl by plants is its total content in soil. The concentration of Tl in rape seeds was observed to be up to 45% of its content in the particular soil. But in many cases, this concentration can substantially exceed the concentration of Tl in soils.

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Received for review November 23, 2004. Revised manuscript received February 24, 2005. Accepted February 28, 2005. Financial support from the Grant Agency of the Czech Republic, Grant No. GA ČR 525/01/0908, and from the Ministry of Education, Youth and Sports of the Czech Republic, Grant MSM 43210001, is gratefully acknowledged.

JF048042K