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Agua regia extractable trace elements in cultivated soils in 1998

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Abstract

This study was part of a three-year (2004-2007) project entitled "Assessment and reduction of heavy metal inputs into Finnish agro-ecosystems" that was funded by the Ministry of Agriculture and Forestry in Finland. The aims of the project were to clarify: 1) *aqua regia* extractable trace elements in Finnish cultivated soils with the international standard method at a national level; 2) *aqua regia* and AAAc-EDTA extractable trace elements in the top- and subsoil of Finnish arable land at selected crop and dairy farms; and 3) field mass balances of trace elements on the selected crop and dairy farms at the farm level.

The main aim of this study was to produce internationally comparable knowledge on the status of cultivated soils in Finland. From the soil material collected during the latest sampling process under the national monitoring programme in 1998, 338 samples were selected for this investigation. The sampling sites were situated evenly over the whole cultivated area in Finland. Samples taken as four sub-samples from the plough layer were analysed for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), vanadium (V) and zinc (Zn) using *aqua regia* extraction according to an international standard method (ISO 11466). General statistical indicators of the analytical results of trace element concentrations are presented by soil type groups and by plant cultivation zones. Distributions of the results into the concentration classes are shown graphically and geographical distributions of the trace element concentrations are presented on the thematic maps.

Index words: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, zinc, arable soil, soil monitoring, Finland

Viljelymaiden seurantaohjelma Suomessa

Hivenalkuaineiden kokonaispitoisuudet peltomaissa vuonna 1998

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Tiivistelmä

Tutkimuksen tavoitteena oli tuottaa kansainvälisesti vertailtavaa tietoa suomalaisten viljelymaiden hivenalkuaineista. Aineistona käytettiin maanäytteitä, jotka oli kerätty kansallisen seurantaohjelman viimeisimmässä näytteiden keruussa vuonna 1998. Kyseisestä aineistosta valittiin 338 maanäytettä, jotka edustivat tasaisesti koko Suomen viljeltyä aluetta. Kukin näyte oli otettu neljänä osanäytteenä pellon muokkauskerroksesta. Näytteistä analysoitiin arseeni (As), kadmium (Cd), kromi (Cr), kupari (Cu), lyijy (Pb), elohopea (Hg), nikkeli (Ni), seleeni (Se), vanadiini (V) ja sinkki (Zn). Analyysi tehtiin kansainvälisen standardimenetelmän ISO 11466:n mukaisesti käyttäen kuningasvesiuuttoa (*aqua regia*). Tuloksista laskettiin tärkeimmät tilastolliset parametrit maalajiryhmittäin ja kasvinviljelyvyöhykkeittäin. Hivenalkuaineiden jakautumisesta pitoisuusluokkiin muotoiltiin graafiset esitykset ja pitoisuuksien maantieteellisestä jakaumasta teemakartat.

Tutkimus oli osa vuosina 2004–2007 toteutettua, Maa- ja metsätalousministeriön rahoittamaa yhteistutkimushanketta ”Raskasmetallikuormitusten arviointi ja vähentäminen Suomen maatalousekosysteemeissä”. Hankkeen tavoitteena oli ensinnäkin selvittää viljelymaiden raskasmetallipitoisuuksia valtakunnallisesti käyttäen kuningasvesiuuttoa. Toiseksi tutkittiin kasvinviljely- ja maidontuotantotilojen viljelymaan raskasmetallipitoisuuksia kuningasvesiuutteesta ja happan (pH 4,65) ammoniumasetaatti-EDTA -uutteesta siten, että näytteet otettiin muokkauskerroksesta ja jankosta. Kolmanneksi hankkeessa analysoitiin raskasmetallien tilakohtaisia peltotaseita kasvinviljely- ja maidontuotantotiloilla.

Avainsanat: aqua regia, arseeni, elohopea, kadmium, kromi, kuningasvesi, kupari, lyijy, nikkeli, seleeni, vanadiini, sinkki, viljelymaa, maaperä, seuranta

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Foreword

This study was part of a three-year (2004-2007) project entitled "Assessment and reduction of heavy metal inputs into Finnish agro-ecosystems" (acronym RAKAS, Project number 310925) that was jointly funded by the Ministry of Agriculture and Forestry in Finland (MMM) and participating organisations. The project was coordinated by MTT Agrifood Research Finland, Plant Production Research (Ritva Mäkelä-Kurtto). Also other scientific staff (Annukka Laitonen) from the same Department participated in the project. Other participating organisations were MTT Laboratories (Merja Eurola), Geological Survey of Finland (Timo Tarvainen, Tarja Hatakka), Evira Finnish Food Safety Authority (Arja Vuorinen, Kimmo Suominen, Riitta Rankanen), Viljavuuspalvelu Ltd (Pirkko Laakso) and Suomen Rehu Ltd (Juha Salopelto). The project was monitored by a steering committee consisting of Senior Officer Pirjo Salminen (MMM), Senior Officer Elina Nikkola (MMM), Dr. Liisa Rajakoski (Ministry of Trade and Industry in Finland), Senior Officer Titta Pasanen (Evira Finnish Food Safety Authority), Dr. Matti Verta (Finnish Environment Institute) and Dr. Kari Kiltilä (Suomen Rehu Ltd). Aims of the project were to study the:

1) total content of trace elements in Finnish cultivated soils with the international standard method at a national level,

2) total content of trace elements in top- and subsoil of Finnish arable land at crop and dairy farms, and the effects of the production sector on possible enrichment or depletion of the trace elements

3) field mass balances of trace elements at a farm level in crop and dairy farms.

The main aim of this part of the project was to produce internationally comparable analytical results on the trace element contents of Finnish cultivated soils at a national level. This study was a continuation of the project "Determination of total and soluble cadmium fractions in cultivated soil for assessing and managing health and environmental risks, acronym CADMIUM, 2001-2002, Project number 310901" supported by the MMM. The samples studied were collected in the national soil monitoring programme of the MTT in 1998. The samples were extracted with *aqua regia* according to the international standard method and analysed for cadmium in the CADMIUM-project. During the RAKAS-project, lead, mercury, copper, chromium, nickel, zinc, vanadium, arsenic and selenium concentrations were measured from these soil extracts. The study was conducted and made at the MTT Agrifood Research Finland, Soil and Plant Production, Jokioinen. All the trace element analyses were carried out by the soil laboratory of the MTT.

List of abbreviations

As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
Hg	Mercury
Ni	Nickel
P	Phosphorus
Pb	Lead
Se	Selenium
V	Vanadium
Zn	Zinc

AR	*Aqua regia*
AAAc	Acid (pH 4.65) ammonium acetate
AAAc-EDTA	Acid (pH 4.65) ammonium acetate –EDTA
Bulk dens.	Bulk density
EDTA	Na_2-ethylenediaminetetracetic acid
El. cond.	Electrical conductivity
dm	Dry matter
fm	Fresh matter
Max	Maximum
Med	Median
Min	Minimum
n	number
Org. C	Organic carbon
OM	Organic matter
Topsoil	Plough layer

Contents

1 Introduction

About 90% of the surface area of Finland is comprised of dry land and about 9% of the land area is comprised of arable land which is about 2 million hectares. The status of Finnish cultivated soils has been studied for agricultural and environmental purposes. Soil testing started in Finland for more than 50 years ago (Vuorinen & Mäkitie 1955, Uusitalo & Salo 2002) and national soil monitoring over 30 years ago (Sippola & Tares 1978, Erviö, et al. 1990, Mäkelä-Kurtto & Sippola 2002).

Finland has one of the oldest soil monitoring programmes for arable land in the Nordic countries. The first national soil survey on trace elements in arable soils was made in 1974 (Sippola & Tares 1978). Then, the number of sampling sites was 2000. In 1987, 1320 of the sites were resampled and the samples analysed for trace elements (Erviö et al. 1990). The third and latest sampling was made in 1998. At that time, the samples were collected from 705 sites. Analytical results were published by Mäkelä-Kurtto and Sippola (2002).

Although the number of sampling sites has diminished, the spatial distribution covers rather well Finnish arable land from the south to the north. In Finnish soil testing and soil monitoring, macro-elements were determined by extracting air-dried samples with acid ammonium acetate (Vuorinen & Mäkitie 1955) and micro-elements with acid ammonium acetate -EDTA (Lakanen & Erviö 1971). These analysis methods have not been in common use in Europe but have been used globally (Sillanpää 1982, Sillanpää & Jansson 1992). Concentrations obtained by these methods indicate exchangeable or easily soluble fractions and thus, also reflect fractions available to plants and mobile to surface and ground waters. Thematic maps on the spatial distribution of the easily extractable trace element fractions in Finnish arable land are available on the MTT´s home page (Mäkelä-Kurtto et al. 2002).

The main aim of this study was to improve the international comparability of the Finnish soil data on arable land. Hence, the trace elements in cultivated soils were analysed for trace elements by using an international standard method (ISO 11466). This method is based on *aqua regia* extraction. Concentrations of the trace elements extracted from the soils in this solution are considered here as total contents. Soil material to be used for analysis was selected from the latest soil monitoring material in 1998. About half of this soil material, totally 338 samples, covering the whole cultivated area in Finland was selected first for the cadmium analysis (Mäkelä-Kurtto et al. 2003). In the present study, nine other trace elements, arsenic, copper, chromium, lead, mercury, nickel, selenium, vanadium and zinc were to be measured from the same *aqua regia* extracts.

2 Material and methods

2.1 Soil samples

The soil samples studied here were collected from 338 sampling sites belonging to the national soil monitoring network in 1998 (Mäkelä-Kurtto & Sippola 2002). The sampling sites were situated on arable land representing the whole cultivated area in Finland (Appendix 1, Fig. 1): 7.7% in the first (I) plant cultivation zone which is the southernmost one, 19.5% in the second (II), 44.1% in the third (III), 22.8% in the fourth (IV) and 5.9% in the fifth (V) zone, which is the northernmost one.

The soil samples were taken as four sub-samples from the plough layer as described by Mäkelä-Kurtto and Sippola (2002). In the laboratory, fresh soil samples were crushed, homogenized and air-dried at 35°C in an oven with air circulation. Air-dried soils were ground, avoiding disintegration of primary particles by pressing the soil with a rotating wooden disc through a 2-mm sieve of hardened steel. The sieved soil was homogenized again and stored at room temperature in cardboard boxes for analyses.

2.2 Soil analyses

Soil samples were analysed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, and zinc by using *aqua regia* (AR) extraction according to the international standard method (ISO 11466). The detailed description of the extraction procedure and the analytical results of cadmium were published by Mäkelä-Kurtto et al. (2003). The same extracts were used here for the determination of the other nine trace elements. From the *aqua regia* extracts arsenic, cadmium, and lead were measured by graphite furnace atomic absorption spectrophotometer, GF-AAS, (Varian GTA-96 Graphite tube atomizer, SpectrAA-400 Zeeman), chromium, copper, nickel, vanadium and zinc by inductively coupled plasma atomic emission spectrophotometer, ICP-AES (Thermo Jarrel Ash, IRIS Advantage), mercury by automatic Hg-analyzer (Varian M-6000A Mercury analyzer, Cetac Technologies Inc.) and selenium by AAS-hydrid device (Varian VGA-76 Vapor generator accessory, SpectrAA-300 Plus).

The carbon (C) content of the samples was determined by an automated dry digestion method (Leco CR-12, St. Joseph, MI, USA), assuming that the sample contained only organic C. Humus content was obtained by multiplying the organic C content by 1.73 (Agricultural Research Centre 1986). Soil pH was measured from the soil-water suspension (1:2.5) (Agricultural Research Centre 1986, Viljavuuspalvelu 2000). To determine a dry matter content of soil material, 5 g of a sample was weighed into a quartz dish. The sample was dried at 105°C for 4 h. The dish was allowed to cool in a desiccator for 2 h. The dried residue in the dish was weighted. Soil type classification was made according to Aaltonen et al. (1949).

All the samples were analysed in the Soil Laboratory of the MTT Laboratories, which are accredited testing laboratories (T024). The quality systems follow the requirements of the standard SFS-EN ISO/IEC 17025. During this study, the MTT Soil Laboratory participated in comparison tests and also arranged for a comparison test on the same ten trace elements studied here (Mäkelä-Kurtto & Kivistö 2005).

2.3 Statistical analyses

Original soil data was stored in Excel files in the MTT network prime where backups are driven regularly. Statistical and graphical processing of the data was performed using SPPS 14 and Excel 2000 software. Analytical results on the trace element concentrations were used for calculating the most important statistical indicators by plant cultivation zones and by soil type groups and for making national thematic maps using the ArcView GIS programme.

3 Results and discussion

According to the particle size distributions (Sippola & Tares 1978) and organic matter contents (Appendix 1, Table 1 and 2) of Finnish cultivated fields (n = 338) studied here, 65% were classified to coarse mineral soils, 15% to clay soils (clay content >30%) and 20% to organic soils (organic matter content >20%). A soil type distribution of these selected fields was nearly the same as that of Finnish arable land (Puustinen et al. 1994) and that of the soil material (n = 705) collected during the monitoring programme in 1998 (Mäkelä-Kurtto & Sippola 2002). The pH values of the fields are presented in Appendix 1 (Table 3 and 4).

A summary on the main statistical indicators on the *aqua regia* extractable trace element contents of the soils is found in Table 1. Recently, the *aqua regia* extraction has more often been used for analysing soils for trace elements. Hence, other investigations on the trace element contents of the Finnish arable land obtained by this method are also available. Hatakka et al. (2007) studied *aqua regia* extractable trace element contents of arable soils on selected crop farms in southwestern Finland (Table 2) and on selected dairy farms in Ostrobothnia (Table 3). Using the same method, Mäkelä-Kurtto et al. (2006) studied cultivated soils in the Tampere region (Table 4) and Mäntylahti and Laakso (2002) in the Mikkeli region (Table 5). Differences in the trace element contents between the regions were mainly caused by the soil type, deposition and agricultural production sector.

Table 1. Statistical indicators on *aqua regia* extractable (ISO 11466) trace element contents (mg kg^{-1} dm) in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998 and analysed in this study.

Element	Minimum	Median	Mean	Maximum
As	0.32	2.76	4.13	17.9*
Cd	0.016	0.153	0.183	0.748
Cr	1.6	22.5	29.4	93.2
Cu	2.7	17.1	21.2	91.6
Hg	0.008	0.039	0.047	0.143**
Ni	1.2	10.0	13.8	46.4
Pb	2.1	8.6	9.7	57.9
Se	0.03	0.18	0.29	1.40***
V	2.7	32.0	39.7	273
Zn	5.7	42.6	54.5	264

* One case 166 mg kg^{-1} dm
** One case 0.949 mg kg^{-1} dm
*** Three cases >1.4 mg kg^{-1} dm (2.3, 3.9 and 5.4)

Various statistical indicators for each trace element studied were separately presented by the soil type groups and plant cultivation zones (Appendix 1). Trace element concentrations greatly varied by soil type groups and by plant cultivation zones. Often, the concentrations were low in coarse mineral soils while the highest concentrations occurred in the clay soils. Instead, the highest concentrations of cadmium, mercury and selenium were measured in the organic soils. Contents of cadmium and lead were higher in the south than in the north because of the centralisation of the population, industry, traffic and their emissions in southern Finland. Regional differences in the trace element concentrations were also partly due to the differences in the soil types. The distribution of the fields to various concentration levels are presented by elements on the histograms in Appendix 2. Spatial distributions of the elements are shown on the thematic maps (Appendix 3) (Mäkelä-Kurtto et al. 2005). Concentrations of arsenic, copper and nickel (Appendix 3, Table 1, 4 and 7) in Finnish cultivated soils geographically seemed to reflect the respective concentrations measured in glacial till by the Geological Survey of Finland (GSF 1992). Statistical correlations calculated between trace element contents are found in Appendix 4.

Mean trace element contents increased in the soil material studied here: Hg < Cd < Se < As < Pb < Ni < Cu < Cr < V < Zn, and in the Earth´s crust (Table 6): Hg = Se < Cd < As < Pb < Cu < Zn < Ni < Cr < V (Sparks 1995). Thus, the arable land seemed to contain more Se, Cu and Zn than the Earth’s crust. Instead, the medians of the trace element contents in arable land were lower than those in the Finnish glacial till (GSF 1992), excluding Pb (Table 6). Differences might result partly from the differences in the analysis methods.

Trace element medians of Finnish cultivated soils were clearly lower than the respective values in global soils (Sparks 1995) (Table 6). Also, the ranges were narrower in the Finnish arable soils than in the global arable soils (ISRIC 1989) (Table 7). However, the Finnish range for Hg was greater than the international one (ISRIC 1989) and for Se greater than the American range. On average, the trace element contents of the Finnish cultivated soils seem to be at the same level as in other Nordic countries (Table 7), but at a lower level than the international ones in arable land (Table 7).

Comparisons with the Finnish background contents presented in the Ordinance of the Council of the State in Finland (OCSF 2007/214) (Table 8) indicated exceeding levels in the Finnish cultivated soils in the case of Cd, Hg, Pb, V and Zn. Anthropogenic enrichment of Cd, Hg, Pb, and also of Cu and Zn in cultivated soils were reported by Tarvainen et al. (2007) depending on the production sector. Trace element contents obtained here were also compared with the critical soil values of the same Ordinance (Table 8). A few cultivated soils in the present study exceeded the low guide value for arsenic, vanadium and zinc and even the high guide value for arsenic and zinc. However, the Finnish vanadium range was inside the respective American range (Sparks 1995) and the zinc range inside the American and international ranges (ISRIC 1989). In addition to this, all the Finnish zinc values were lower than the respective Swedish limit for polluted soil (Xin 2005) (Table 9).

Table 2. Statistical indicators on *aqua regia* extractable (ISO 11466) trace element contents (mg kg^{-1}) in the topsoil (plough layer) of 23 fields at five crop farms in southwestern Finland in 2004. A mean value was not computed if over 50% of element contents were below detection limit (Hatakka et al. 2007).

Element	Minimum	Median	Mean	Maximum
As	3.1	6.0	5.9	12
Cd	0.150	0.200	0.227	0.580
Cr	22	67	68	106
Cu	13	29	32	60
Pb	11	20	20	31
Hg*	<0.01	0.044	0.047	0.139
Ni	10	33	33	54
Se	<0.2	<0.2	-	0.860
V	31	94	90	167
Zn	46	124	114	165

* Pyrolytic determination

Table 3. Statistical indicators on *aqua regia* extractable (ISO 11466) trace element contents (mg kg^{-1}) in the topsoil (plough layer) of 21 fields at five dairy farms in Ostrobothnia in 2004. A mean value was not computed if over 50% of element contents were below detection limit (Hatakka et al. 2007).

Element	Minimum	Median	Mean	Maximum
As	1.0	2.6	3.1	11
Cd	0.020	0.100	0.112	0.240
Cr	9	22	25	59
Cu	3.5	13	14	38
Pb	2.4	6.8	6.7	14
Hg*	0.011	0.025	0.033	0.079
Ni	3.7	8.7	11	21
Se	0.230	0.310	0.422	0.880
V	11	40	43	135
Zn	16	35	42	72

* Pyrolytic determination

Table 4. Statistical indicators on *aqua regia* extractable (ISO 11466) trace element contents (mg kg^{-1} dm) in the topsoil (plough layer) of 15 fields at thirteen farms in the Tampere region (Mäkelä-Kurtto et al. 2006).

Element	Minimum	Median	Mean	Maximum
As	2.90	3.90	4.06	6.80
Cd	0.13	0.20	0.21	0.35
Cu	15.3	21.2	22.7	35.5
Cr	26.9	45.5	48.1	73.5
Ni	9.21	19.7	20.6	34.4
Pb	8.43	12.0	12.5	17.2
V	47.9	60.3	64.4	94.5
Zn	71.5	103	107	152
Se	0.14	0.20	0.20	0.32

Table 5. Ranges of *aqua regia* extractable (ISO 11466) trace element contents (mg kg^{-1}) in agricultural soils (n = 312) in the Mikkeli region in 2000 and Finnish limit values for “Clean Soil” proposed by Mäntylahti and Laakso (2002).

Element	Mikkeli 2000		”Clean Soil”2002	
	Mineral soils (n = 274)	Organic soils (n = 38)	Mineral soil	Organic soil
	Range	Range	Limit	Limit
As	0.85-29.4	0.45-20.2	10	10
Cd	0.045-0.426	0.033-0.305	0.3	0.3
Cr	6.6-45.6	3.9-19.9	70	70
Cu	4.9-33.0	4.0-51.9	35	35
Pb	3.1-18.4	2.5-42	20	20
Hg	0.046-0.291	0.046-0.184	0.10	0.15
Ni	3.6-18.3	1.6-10.7	35	25
Zn	9.9-95.0	5.4-40.5	100	100

Table 6. Trace element contents in Finnish arable soils (n = 338)[1], global soils[2], American soils[3], Earth´s crust[4] and glacial till in Finland[5].

	Finnish Median[1] mg kg $^{-1}$ dm	**Finnish Range[1]** mg kg $^{-1}$ dm	**Global Median[2]** mg kg $^{-1}$	**American Range[3]** mg kg $^{-1}$	**Earth´s crust Mean[4]** mg kg $^{-1}$	**Finnish glacial till Median[5]** mg kg $^{-1}$
As	2.8	0.32-18	6	0.10-40	1.5	2.6
Cd	0.153	0.016-0.748	0.35	0.01-2	0.11	n.a.
Cr	23	1.6-93	70	5-1,500	100	60
Cu	17	2.7-92	30	2-250	50	20
Pb	9	2.1-58	35	2-300	14	2.5
Hg	0.039	0.008-0.949	0.06	0.01-0.50	0.05	n.a.
Ni	10	1.2-46	50	2-750	80	24
Se	0.180	0.030-5.4	0.4	<0.1-4.3[3]	0.05	n.a.
V	32	2.7-273	90	3-500	160	79
Zn	43	5.7-264	90	1-900	75	57

[1]Present study; [2]Sparks 1995: global soils; [3]Sparks 1995: American soils; [4]Sparks 1995: Earth´s crust; and [5]GSF 1992.

Table 7. Mean total contents of trace elements (mg kg^{-1} dm) in the plough layer of arable soils in Finland (present study), Sweden (Eriksson et al. 1997) and Norway (Amundsen et al. 1995) and national and international (ISRIC 1989) ranges (n = number of samples).

	Finland 1998 Mean (Range)	**Sweden 1988-95** Mean (Range)	**Norway 1985** Mean (Range)	**ISRIC 1989** (Range)
n	338	1720	1500	-
As	4 (0.32-18)	4 (<0.1-78.9)	-	(0.1-40)
Cd	0.18 (0.016-0.748)	0.22 (0.02-2.20)	0.22	(0.01-1.0)
Cr	29 (1.6-93)	19 (1.3-68)	27	(5-500)
Cu	21 (2.7-92)	14 (1.1-102)	19	(2-100)
Pb	10 (2.1-58)	17 (3.6-100)	24	(2-200)
Hg	0.05 (0.008-0.95)	0.04 (<0.01-0.59)	0.05	(0.1-0.5)
Ni	14 (1.2-46)	12 (0.7-110)	21	(5-500)
Se	0.29 (0.03-5.4)	0.31 (0.03-13)	-	-
V	40 (2.7-273)	35 (2-202)	-	-
Zn	55 (5.7-264)	56 (5-185)	64	(10-300)

Table 8. Background, threshold, low guide and high guide contents (mg kg^{-1}) of trace elements for the evaluation of soil contamination and restoration in Finland (OCSF 2007/214).

	Background content*	Threshold content	Low guide content	High guide content
As	1 (0.1-25)	5	50 (e)	100 (e)
Cd	0.03 (0.01-0.15)	1	10 (e)	20 (e)
Cr	31 (6-170)	100	200 (e)	300 (e)
Cu	22 (5-110)	100	150 (e)	200 (e)
Hg	0.005 (<0.005-0.05)	0.5	2 (e)	5 (e)
Ni	17 (3-100)	50	100 (e)	150 (e)
Pb	5 (0.1-5)	60	200 (h)	750 (e)
Se	-	-	-	-
V	38 (10-115)	100	150 (e)	250 (e)
Zn	31 (8-110)	200	250 (e)	400 (e)

*measured in fine-grained glacial till, (e) = based on ecological criteria; (h) = based on health criteria

Table 9. Reference values for trace element contents (mg kg^{-1} dm) in Swedish soils. Reference values are the 90th percentiles of levels measured in connection with the Swedish Geological Survey´s (SGS) geochemical soil survey, and with the Environmental Protection Agency´s (SEPA) soil sampling of the urban environment (Xin 2005).

	SGS	SEPA*		Swedish limit
	Moraine*	Moraine	Sedimentary soils	
As	10	10	7	15
Cd		0.3	0.15	0.4
Cr (valid if Cr VI is not present)		30	45	120
Cr VI				5
Cu				100
Pb	20	25	25	80
Hg		0.1	0.2	1
Ni	20	25	30	35
Se				
V		40	60	120
Zn	60	70	100	350

Mäntylahti and Laakso (2002) made a relatively large study of the trace element contents in the cultivated soils in the Mikkeli region. Based on their research results (Table 5), they proposed limit values for the “Clean Soils” in Finland (Table 5). The limit values are nearly the same for mineral and organic soils. The limit value for mercury is higher and for nickel lower for organic soils than for mineral soils. Approximately 20% of copper and nickel contents, 15% of cadmium and zinc contents and 5% of arsenic, chromium, lead and mercury contents obtained in the present study exceeded the "Clean values". It is worth noting that the clay soils in southern Finland are much richer in trace elements than the coarse mineral soils in the Mikkeli region.

Currently, there are no official limit values for trace elements particularly for cultivated soils in Finland. There are separate limit values for arable land in Canada (Table 10). Due to the similarity in climate and soil formation in Canada and Finland, it was reasonable to compare the Finnish trace element contents with the respective Canadian limit values (CCME 2003). As Table 10 shows, all the cadmium, lead, mercury, and nickel contents in the Finnish cultivated soils studied here were lower than the Canadian limits. Some exceeding values occurred in the case of arsenic, copper, selenium, vanadium and zinc. Instead, 7% of the Finnish soils contained chromium more than is allowed in Canada (Table 10). In Sweden, a guideline value for chromium in polluted soils is 120 mg kg^{-1} dm and is valid only if Cr VI is not present (Xin 2005) as seen in Table 9. The Finnish maximum for the chromium content was 93 mg kg^{-1} and clearly lower than the Swedish limit. In addition, there is a limit value for Cr VI in Sweden (Xin 2005), which is 5 mg kg^{-1} dm.

Table 10. Canadian limit values for arable land (CCME 2003) and percentages (%) of Finnish soils (n = 338) under (Class 1) and above (Class 2) the limits.

Element	Limit value for arable land in Canada mg kg^{-1} dm	Class 1 %	Class 2 %
As	12	98	2
Cd	1.4	100	0
Cr	64	93	7
Cu	63	98	2
Pb	70	100	0
Hg	6.6	100	0
Ni	50	100	0
Se	1	97	3
V	130	> 99	< 1
Zn	200	99	1

3.1 Arsenic

Statistical indicators of the arsenic contents measured here in cultivated soils are presented in Appendix 1 (Table 5 and 6). The contents varied from 0.32 to 18 mg kg^{-1} dm. The mean of the whole study material was 4.1 and the median 2.8 mg kg^{-1} dm. More than 50% of the analytical results were between 2 and 4 mg kg^{-1} dm and more than 95% <10 mg kg^{-1} dm. Clay soils had notably higher arsenic concentrations than the other soil types. The lowest concentrations occurred in coarse mineral soils. Also, research results obtained by Hatakka et al. (2007) showed that As contents were higher in the clay soils than in the coarse mineral soils. Due to the clay soils, the biggest concentrations were found in southern Finland (the plant cultivation zones I and II) where the mean arsenic contents were twice the means in other parts of Finland (the zones III-V). Spatially, low arsenic values occurred in cultivated soils in eastern and northern Finland similar to the way as they occurred in glacial till (GSF 1992).

According to Mäntylahti and Laakso (2002), the mean and median concentration of *aqua regia* extractable As in the cultivated soils in the Mikkeli region was 3.2 and 2.9 for mineral soils and 4.4 and 2.8 mg kg^{-1} for organic soils. Due to coarse mineral soils, As contents in the Mikkeli region were rather low, on average. However, relatively high values, like 35 mg kg^{-1} in a mineral soil also occurred.

Particularly high As concentrations in glacial till, and pore ground water have been detected by the GSF (1992) in the Tampere region due to the high As concentration in the soil parent material. However, As contents of cultivated soils in that region were at a normal national level (Mäkelä-Kurtto et al. 2006, Mäkelä-Kurtto et al. 2007a).

According to the OCSF 2007/214, background As contents in soil may vary from 0.1 to 25 mg kg^{-1}. Only one site in the national monitoring programme 1998 (in the plant cultivation zone II) had an exceptionally high arsenic content, 166 mg kg^{-1} dm, and exceeded the background values. This site was a real exception, a "hot spot" because it was about 40 times bigger than a mean concentration of the whole country and may be a sign of pollution. In this site, the soil type was coarse mineral soil, with an organic carbon (C) content 7.02% and pH(H_2O) of 5.71. Also, the contents of most other elements (Cd 0.456, Cr 55.92, Cu 27.55, Ni 26.53, V 73.26, Zn 89.29, Se 0.40, Hg 0.091 and Pb 9.3 mg kg^{-1} dm) were above the national mean levels. The As source could not be clarified.

The arsenic figures for the Swedish agricultural soils during the period of 1988-1995 were 4.0 and 3.2 mg kg^{-1} dm (Eriksson et al. 1997). In Sweden, arsenic contents in the plough layer closely varied in relation to the As content in the subsoil. An arsenic range for international arable land varied from 0.1 to 40 mg kg^{-1} dm (ISRIC 1989).

Mäntylahti and Laakso (2002) proposed a 10 mg kg^{-1} for a "Clean Soil" value for As in arable soil. More than 95% of the As contents obtained here were lower than the proposed value. In Canada, the environmental quality guideline for arsenic in agricultural soils is 12 mg kg^{-1} (CCME 2003). In Finland, As contents in about 1% of the cultivated soils studied exceeded Canadian guideline value. In Sweden, the limit value for As is 15 mg kg^{-1} dm (Xin 2005).

3.2 Cadmium

Aqua regia extractable Cd contents in the Finnish cultivated soils varied from 0.016 to 0.748 mg kg^{-1} dm (Table 1). In general, the range of background values in soils is narrow, between 0.01-0.15 mg kg^{-1} (OCSF 2007/214). However, the Finnish cadmium range of arable land was clearly lower than the respective international range, 0.01-1.0 mg kg^{-1} dm (Table 6) (ISRIC 1989). A median Cd concentration in cultivated soils in Finland was 0.15, in Sweden 0.18 (Eriksson et al. 1997) and in Norway 0.14 mg kg^{-1} dm (Amundsen et al. 1995) (Table 7). The range of the soil cadmium contents was quite large in other European countries (AROMIS 2005).

Analytical results for cadmium are shown by the soil type groups and plant cultivation zones in Appendix 1 (Table 7 and 8). The highest mean Cd concentrations (0.30 mg kg^{-1} dm) were found in organic soils and the lowest (0.14 mg kg^{-1} dm) in coarse mineral soils. Clay soils contained Cd 0.22 mg kg^{-1} dm, on average. Cultivated soils in the Mikkeli region had a Cd mean for mineral soils of 0.10 and for organic soils 0.28 mg kg^{-1} (Mäntylahti & Laakso 2002). Fields (n = 23) in crop farms in the southwestern Finland contained cadmium 0.23 mg kg^{-1} and fields (n = 21) in Ostrobothnia 0.11 mg kg^{-1} (Hatakka et al. 2007), on average. Differences were mainly caused by the soil types. In the Tampere region, the mean cadmium content was 0.21 mg kg^{-1} dm (Mäkelä-Kurtto et al. 2006).

The mean cadmium content measured here for the soil material collected in 1998 (0.18 mg kg^{-1} dm) was lower than the mean (0.21 mg kg) for the soil material collected in the monitoring programme in 1974 (Sippola & Mäkelä-Kurtto 1986). This could be an indicator of the decrease of Cd inputs from P-fertilizers and from atmospheric Cd deposition. Since 1980, the use of low-cadmium Finnish apatite from the Siilinjärvi mine has increased in the production of P-fertilizers in Finland, thus decreasing the Cd content in Finnish P-fertilizers. AAAc-EDTA extractable Cd concentrations increased from 1974 to 1987 by 30% (Erviö et al. 1990), but levelled from 1987 to 1998 (Mäkelä-Kurtto & Sippola 2002), particularly because Cd inputs from fertilizers radically diminished. Scenarios obtained by the dynamic EU-model calculations indicated (Louekari et al. 2000) that if low-Cd P-fertilizers could be used for fertilization in Finland in the future as well, no Cd would accumulate in Finnish cultivated soils.

The threshold value for soil Cd in Finland is 1 mg kg^{-1} (OCSF 2007/214). All the Cd contents measured here remained under this value. In Canada, the Cd limit for arable soils is 1.4 mg kg^{-1} (CCME 2003) and in Sweden for all soils 0.4 mg kg^{-1} dm (Xin 2005). In Finland, Mäntylahti and Laakso (2002) proposed 0.3 mg kg^{-1} for a limit value for “Clean Soil” to be applied for arable land. Over 75% of the Cd contents obtained here were lower than the “Clean Soil” value. The distribution of the soils to the different Cd concentration classes are presented in a histogram (Appendix 2, Fig. 2).

The spatial distribution of Cd contents is described on the thematic map (Appendix 3, Fig. 2). The Cd contents were higher in the south than in the north, due to soil types and anthropogenic reasons. The thematic map on the *aqua regia* extractable cadmium was quite similar to the respective map on the AAAc-EDTA extractable cadmium (Mäkelä-Kurtto et al. 2002).

3.3 Chromium

For the soils studied, chromium contents varied from 1.6 to 93 mg kg^{-1} dm, with a mean of 29 and a median of 23 mg kg^{-1} dm (Table 1). The Cr concentration in the soil is known to be greatly dependent on the parent material. A normal background range in soil for Cr is between 6 and 170 mg kg^{-1} (OCSF 2007/214) and globally arable soils between 5 and 500 (ISRIC 1989). The Earth´s crust contains about 100 mg kg^{-1} Cr (Sparks 1995) and glacial till in Finland 60 mg kg^{-1} (GSF 1992). In Finland, the threshold value for Cr is 100 mg kg^{-1} (OCSF 2007/214). All the Cr contents measured in this study were within the natural background range. In Sweden, agricultural soils contained 21 mg kg^{-1} (Eriksson et al. 1997) chromium and in Norway 28 mg kg^{-1} (Amundsen et al. 1995), on average. Higher Cr contents occurred in other European countries (AROMIS 2005).

The Canadian limit value for Cr in the cultivated soils is 64 mg kg^{-1} dm (CCME 2003) and the Finnish "Clean Soil" value 70 mg kg^{-1} dm (Mäntylahti & Laakso 2002). About 95% of Finnish soils studied can be considered as "clean". The Swedish limit for total Cr is 120 mg kg^{-1} dm, if no Cr VI is present and for Cr VI 5 mg kg^{-1} dm (Xin 2005).

In clay soil areas in Finland, the mean Cr concentration was over twice as high as in the areas of coarse mineral soils or in organic soils (Appendix 1, Table 9). Hence, the highest mean values were observed in cultivation zones I and II (Appendix 1, Table 10). According to Hatakka et al. (2007), Cr contents in southwestern Finland was 68 mg kg^{-1} and in Ostrobothnia 25 mg kg^{-1}. In the Mikkeli region, a mean Cr concentration for mineral soils was 18 mg kg^{-1} and for organic soils 15 mg kg^{-1} (Mäntylahti & Laakso 2002), on average. Low values in the Mikkeli region can be clarified by the small number (3) of the clay soils there. In the Tampere region, the respective Cr value was 48 mg kg^{-1} dm (Mäkelä-Kurtto et al. 2006).

The thematic map (Appendix 3, Fig. 3) showed that high Cr contents occurred in the southwestern clay areas, but also in cultivated soils in northern Finland, where glacial till also had high Cr contents (GSF 1992). In Sweden, the Cr concentration in the plough layer correlated well with the Cr concentration in the subsoil, indicating that high Cr concentrations in cultivated soils in most cases originates from the soil parent material (Eriksson et al. 1997). The present study shows that chromium was clearly connected to the clay and thus, highly correlated to nickel, vanadium and zinc (Appendix 4, Table 1).

3.4 Copper

The Cu contents of the national soil monitoring material varied from 2.7 to 92 mg kg^{-1} dm, the median and mean being 17 and 21 mg kg^{-1} dm, respectively (Appendix 1, Table 11 and 12). According to the OCSF 2007/214, the background Cu contents in soil may vary from 5 to 110 mg kg^{-1} and the threshold value for Cu is 100 mg kg^{-1}. All the Cu contents measured here were of normal background range. Internationally, Cu contents in cultivated soils varied between 2 and 100 mg kg^{-1} dm (ISRIC 1989). Mäntylahti and Laakso (2002) proposed 35 mg kg^{-1} as a "Clean Soil" value for arable land. More than 80% of the soils studied contained Cu less than 35 mg kg^{-1} dm (Appendix 2, Figure 4). In Canada, the limit value of Cu for arable soils is 63 mg kg^{-1} dm (CCME 2003). About 2% of the Cu contents measured here exceeded this value. The Swedish limit for soil Cu is 100 mg kg^{-1} dm (Xin 2005).

The Cu contents were the highest in the organic soils and lowest in the coarse mineral soils (Appendix 1, Table 11 and 12). A variation in the concentrations between the plant cultivation zones seemed to be dependent mainly on the soil type distribution. Clay soils in southern Finland seemed to be rich in Cu according to Hatakka et al. (2007). A spatial distribution of *aqua regia* extractable Cu (Appendix 3, Figure 4) had similarities with that of AAAC-EDTA extractable Cu of the larger monitoring soil material in 1998 (Mäkelä-Kurtto et al. 2006). Also, some regional similarities could be found between the Cu contents in glacial till (GSF 1992) and Cu contents in the cultivated soils in southwestern, eastern and northern Finland.

The mean Cu contents in the Finnish, Swedish (Eriksson et al. 1997) and Norwegian (Amundsen et al. 1995) arable soils were of the same level, but lower than the mean in the Earth´s crust (Sparks 1995). The Cu contents in other European countries could be higher than those in the Nordic countries (AROMIS 2005).

3.5 Lead

Lead contents in the fields studied here ranged from 2.1 to 58 mg kg^{-1} dm (Table 1). A natural background range varies from 0.1 to 5 (OCSF 2007/214). It is obvious that in the 1900´s, Pb emissions from traffic have increased Pb contents in soils all over the world. In Finland, Pb emissions from traffic have decreased dramatically since the 1970´s and fell to the nearly zero-level after 1994, when unleaded gasoline was used in all motor vehicles (Mäkelä 1996).

According to ISRIC (1989), Pb contents in arable soils varied between 2 and 200 mg kg^{-1} internationally. A threshold value for Pb presented in the Ordinance mentioned above is 60 mg kg^{-1}. Thus, all the Pb contents obtained here for cultivated soils were under the threshold value. The limit value for Pb in agricultural soils in Canada is 70 mg kg^{-1} dm (CCME 2003). In Sweden, the limit value for Pb in soils is 80 mg kg^{-1} dm (Xin 2005). In Finland, a "Clean Soil" must not contain more than 20 mg kg^{-1} Pb (Mäntylahti & Laakso 2002). More than 95% of the soils studied here could be considered as "Clean Soil".

The mean and median of the fields was 8.6 and 9.7 mg kg^{-1} dm, respectively (Table 1). The Earth´s crust contains about 14 mg kg^{-1} Pb (Sparks 1995). The natural occurrence of lead in soils is strongly related to the composition of the bedrock (Kabata-Pendias & Pendias 1984). The mean Pb content in arable soils in Sweden (Eriksson et al. 1997) was 17 mg kg^{-1} dm and in Norway 24 mg kg^{-1} (Amundsen et al. 1995). The Pb content in Finnish soils was clearly lower than in the Swedish or Norwegian soils, on average. In areas of high traffic density in Europe, high Pb contents were also reported (AROMIS 2005).

Clay soils clearly contained more Pb than the coarse mineral soils or organic soils (Appendix 1, Table 13 and 14). According to Hatakka et al. (2007) arable soils on crop farms in southwestern Finland contained 20 mg kg^{-1} and arable soils on dairy farms in Ostrobothnia contained 6.7 mg kg^{-1} Pb, on average. In the Tampere region, the mean Pb content was 13 mg kg^{-1} dm (Mäkelä-Kurtto et al. 2006) and in the Mikkeli region, the median of the mineral soils was 7.7 and the organic soils was 11 mg kg^{-1} (Mäntylahti & Laakso 2002). The main reasons for higher contents in the south were the clay soils, traffic and to some extent the production sector, as well. A decreasing trend from the south to the north could be seen in Table 14 (Appendix 1) and on the thematic map Figure 5 (Appendix 3).

3.6 Mercury

In the national soil monitoring material in 1998, a range of Hg contents was from 0.008 to 0.143 mg kg^{-1} dm (Table 1), but in one case, the Hg content was as high as 0.949 mg kg^{-1} dm. Background values in soils vary between 0.005 and 0.05 mg kg^{-1} (OCSF 2007/214). The Earth´s crust contains about 0.05 mg kg^{-1} Hg (Sparks 1995). According to ISRIC (1989), Hg contents of arable soils may vary internationally from 0.1 to 0.5 mg kg^{-1} dm.

In this study, the Hg median and mean was 0.039 and 0.047 mg kg^{-1} dm, respectively. Mercury tends to appear more in organic than in clay or coarse mineral soils (Appendix 1, Table 15 and 16). Organic soils had twice as much Hg as mineral soils, on average. Mäkelä-Kurtto and Sippola (1986) studied Hg contents of the selected cultivated soils (n = 361) collected during the 1974 monitoring programme. Based on their studies, organic soils (n = 98: a mean 0.116 mg kg^{-1}) contained more Hg than clays (n = 48: a mean 0.049 mg kg^{-1}) or coarse mineral soils (n = 215: a mean 0.048 mg kg^{-1}). In addition to this, they reported differences in the Hg contents between the soil types inside the organic soils. The Hg mean for Carex peat samples (n = 51) was 0.134, mould samples (n = 39) 0.103 and Sphagnum Carex peat samples (n = 8) 0.060 mg kg^{-1}. High Hg contents in organic soils could be clarified partly by the low volume weight of these soils.

Also, the national thematic map on mercury contents in 2004 is presented (Appendix 3, Fig. 6.). According to the map, the highest contents seemed to occur in the peat regions (Kurki 1972). Hatakka et al. (2007) reported a mean Hg content of 0.047 mg kg^{-1} in southwestern Finland and 0.033 mg kg^{-1} in Ostrobothnia. Mäntylahti and Laakso (2002) reported an Hg median of 0.060 for mineral soils and 0.200 mg kg^{-1} for organic soils in the Mikkeli region. In general, Hg contents in the Mikkeli region were relatively low, and the range for organic soils was lower than for mineral soils.

In Sweden, cultivated soils contained 0.04 mg kg^{-1} dm Hg (Eriksson et al. 1997) and in Norway 0.05 mg kg^{-1} dm (Amundsen et al. 1995) on average. Thus, Hg contents in Nordic countries seem to be at the same level. Obviously, the abundance of peat soils and the high organic matter content of arable soils in Finland and the Nordic countries resulted to higher Hg levels than those reported from other countries (ISRIC 1989).

The threshold content of Hg for the Finnish soils is 0.5 mg kg^{-1} and the low guide content 2 mg kg^{-1} (OCSF 2007/214). About 75% of mineral soils but less than 25% of organic soils studied in the present study remained under the threshold value (Appendix 1, Table 15). In Sweden, the limit value for polluted soil is 1 mg kg^{-1} dm (Xin 2005) and in Canada, for agricultural land 6.6 mg kg^{-1} (CCME 2003). A Finnish "Clean Soil" value for mineral soils is 0.10 and for organic soil 0.15 mg kg^{-1} (Mäntylahti & Laakso 2002). Based on this, only a few fields in this study could be considered "Clean". The biggest source of Hg into the cultivated soils has been Hg containing pesticides (Mäkelä-Kurtto 1987, 1998). However, the use of Hg as an active ingredient in pesticides was banned in Finland in 1990. In Sweden, the Hg content in the plough layer was 2.5 times that of the subsoil (Eriksson et al. 1997) indicating anthropogenic accumulation of Hg in arable soil.

3.7 Nickel

A Ni range of the Finnish arable soils in 1998 was from 1.2 to 46 mg kg^{-1} (Table 1), while the respective international range was from 5 to 500 mg kg^{-1} (ISRIC 1989). According to the OCSF 2007/214, natural Ni contents in soils vary between 3 and 100 mg kg^{-1}. According to this study, arable soils contained Ni 14 mg kg^{-1} in Finland, 12 in Sweden (Eriksson et al. 1997), and 21 mg kg^{-1} in Norway (Amundsen et al. 1995), on average. The mean Ni in the Finnish glacial till is 24 (GSF 1992) and in the Earth´s crust is about 80 mg kg^{-1} (Sparks 1995).

A mean Ni content in clay soils was twice that in other soil types (Appendix 2, Table 17 and 18). Nickel abundance was clearly connected to clay soils. Hence, Ni was highly correlated to chromium and vanadium (Appendix 4, Table 1). Ni-rich arable land was situated in the southwestern, eastern and northern parts of Finland (Appendix 3, Fig. 7), like Cr- and V- rich soils. Ni-rich soils were in the same areas as Ni-rich glacial till (GSF 1992).

Ni contents in Finnish cultivated soils have been reported to range between 10 and 54 mg kg^{-1} in southwestern Finland and between 3.7 and 21 in Ostrobothnia (Hatakka et al. 2007), between 9.2 and 34 mg kg^{-1} dm in the Tampere region (Mäkelä-Kurtto et al. 2006) and between 1.6 and 18 mg kg^{-1} in the Mikkeli region (Mäntylahti & Laakso 2002). In this study, the highest Ni contents spatially occurred in the clay area of southwestern Finland, as presented in thematic map on Ni (Appendix 3, Fig. 7).

A Finnish threshold value for Ni is 50 mg kg^{-1} (OCSF 2007/214). It is the same as the limit value for Ni for arable soils in Canada (CCME 2003). All the Ni contents obtained in this study were under 50 mg kg^{-1}. The low guide value of the OCSF 2007/214 is 100 mg kg^{-1}. However, the limit value in Sweden is very low, 35 mg kg^{-1} (Xin 2005). Mäntylahti and Laakso (2002) proposed 35 mg kg^{-1} for the highest Ni content for "Clean Mineral Soils" and 25 mg kg^{-1} for "Clean Organic Soils". On this basis, at least 80% of the fields studied here seem to be "Clean Soil" (Appendix 2, Fig. 7).

3.8 Selenium

Selenium contents in Finnish cultivated soils in 1998 varied widely, from 0.03 to 5.4 mg kg^{-1} dm (Table 1). However, 95% of the coarse mineral soils, clay soils and organic soils contained less than 0.34, 0.55 and 1.17 mg kg^{-1} dm Se (Appendix 2, Table 19 and 20), respectively. Organic soils had three times higher Se content than coarse mineral soils, on average. A mean Se content for the whole country was 0.29 mg kg^{-1} dm (Table 1). In Sweden, the average content of Se in arable fields was 0.31 mg kg^{-1} (Eriksson et al. 1997). The global median is 0.4 and the American range <0.1 - 4.3 mg kg^{-1} (Sparks 1995). In Canada, the environmental quality guideline for Se in arable land is 1 mg kg^{-1} dm (CCME 2003). About 3% of Finnish agricultural soils studied here had the Se content higher than the Canadian guideline value.

The spatial distribution of the Se contents in Finnish arable soils is presented on the thematic map (Appendix 3, Fig. 8). In the Vaasa region, there seems to be fields containing more Se than elsewhere in Finland. Regionally, Se content varied from 0.14 to 0.32 mg kg^{-1} dm in the Tampere region (Mäkelä-Kurtto et al. 2006), from <0.2 to 0.86 in southwestern Finland and from 0.23 to 0.88 mg kg^{-1} in Ostrobothnia (Hatakka et al. 2007). It would be very important to monitor the Se content in cultivated soils in Finland because several grams annually per hectare via the mineral fertilizers and feed stuffs of Se is added into the soils (Eurola et al. 2007, Mäkelä-Kurtto et al. 2007b).

3.9 Vanadium

Vanadium is a common element in the lithosphere and this trace element had a large concentration range in the cultivated soils in 1998. The contents varied between 2.7 and 273 mg kg^{-1} dm (Table 1). In unpolluted soils, V contents vary from 10 to 115 mg kg^{-1} with a mean of 38 mg kg^{-1} (OCSF 2007/214). The mean V content in the Finnish glacial till is 79 mg kg^{-1} (GSF 1992) and in the Earth´s crust 160 mg kg^{-1} (Sparks 1995). The mean of arable soils in Finland was 40 mg kg^{-1} dm (Table 1). A respective figure for the Swedish soils was 35 mg kg^{-1} (Eriksson et al. 1997). The global median is 90 and the American range 3 - 500 mg kg^{-1} (Sparks 1995).

The official threshold value for soil V in Finland (OCSF 2007/214) is 100 mg kg^{-1}. The low guide content is 150 and the high guide content 250 mg kg^{-1}. Totally, there were seven cases of Finnish soils exceeding the threshold value and one case exceeding even the high guide value. In Sweden, the soil limit value for V is 120 mg kg^{-1} (Xin 2005). The Canadian limit for agricultural soils is 130 mg kg^{-1} dm (CCME 2003). Two cases measured here exceeded the Canadian limit value (Table 10 and APPEDIX 2, Fig. 9).

Vanadium occurred more in clay soils than in coarse mineral soils or organic soils (Appendix 1, Table 21 and 22). The contents in clay soils were almost twice or even three times as high as in the other soil types. Hence, the spatial distribution of the V contents (Appendix 3, Fig. 9) reflects the spatial distribution of the clay soils, too. Vanadium was highly correlated to Cr and Ni and to some extent to zinc (Appendix 4, Table 1) because clays are rich in all these elements. the clay effect could also be seen in the regional distribution of V contents obtained in other investigations. Arable soils in southwestern Finland contained 90 mg kg^{-1} of vanadium, in Ostobothnia 43 mg kg^{-1} (Hatakka et al. 2007) and in the Tampere region 64 mg kg^{-1} dm (Mäkelä-Kurtto et al. 2006).

3.10 Zinc

Of the trace elements studied here, zinc was the most abundant trace element in the Finnish cultivated soils in 1998, with a median and a mean of 43 and 55 mg kg^{-1} dm, respectively (Table 1). The median Zn value for the Finnish glacial till is 57 mg kg^{-1} (GSF 1992). The Zn contents obtained in this study ranged from 5.7 to 264 mg kg^{-1} dm. According to ISRIC (1989), Zn contents in arable soils vary between 10 and 300 mg kg^{-1}. Natural background values in Finland vary between 8 and 110 mg kg^{-1} (OCSF 2007/214). Totally, 28 soils studied here exceeded the natural background range, four soils exceeded the threshold value, 200 mg kg^{-1}, and even one exceeded the low guide value, 250 mg kg^{-1} (OCSF 2007/214). A mean for Zn in Swedish cultivated soils is 56 mg kg^{-1} dm (Eriksson et al. 1997) and in Norwegian soils 64 mg kg^{-1} dm (Amundsen et al. 1995).

The highest Zn contents appeared in clays and the lowest ones in organic soils (Appendix 1, Table 23 and 24). That results in high correlations of Zn to Cr, Ni and V (Appendix 4, Table 1). Also, other investigations show that Zn contents are high in clay soils, 90 mg kg^{-1}, on average, in southwestern Finland, as compared to the respective value in coarser mineral soils, 43 mg kg^{-1} in Ostrobothnia (Hatakka et al. 2007). However, an exceptionally high mean value, 107 mg kg^{-1} dm, was found in the arable soils in the Tampere region (Mäkelä-Kurtto et al. 2006).

The Canadian limit value for arable soils is 200 mg kg^{-1} dm (CCME 2003) which is the same as the Finnish threshold value (OCSF 2007/214). In Sweden, the soil limit value for Zn is 350 mg kg^{-1} dm (Xin 2005). The Finnish "Clean Soil" value for agricultural soils is 100 mg kg^{-1} (Mäntylahti & Laakso 2002). Practically all the organic soils, and about 90% of the mineral soils were "Clean" in this study (Appendix 1, Table 23).

The thematic map on Zn (Appendix 3, Fig. 10) indicates that southwestern Finland, including the Tampere region, had relatively high Zn contents in the arable soils. High Zn contents that occurred in the clay area in the southwestern Finland clearly came out in the spatial distribution of Zn.

4 Conclusions

This study was the first nationwide survey on *aqua regia* extractable trace elements in Finnish cultivated soils. The survey consisted of a relatively large number of sampling sites and trace elements that were determined by using an international standard method. This study gives an opportunity to compare the trace element contents of Finnish arable soils directly with the respective international and other national values.

Trace element contents in Finnish cultivated soils were of the same level as in other Nordic countries, but lower than those reported in many other European countries.

When the trace element contents were compared to the respective natural background contents measured in the Finnish fine-grained glacial till, elevated contents seemed to occur in the cases of Cd, Pb and Hg in the cultivated soils. Obviously, the main reasons were anthropogenic, atmospheric deposition for Pb, P-fertilizers for Cd and pesticides for Hg. However, Cd and Pb contents in Finnish arable land were internationally low.

This nationwide trace element survey forms a fundamental basis for a monitoring programme on Finnish arable land. To recognize and manage health and ecological risks, it is important to follow up the trace element trends in cultivated soils in the coming years.

5 Summary

This study was part of a three-year (2004-2007) project entitled "Assessment and reduction of heavy metal inputs into Finnish agro-ecosystems" that was funded by the Ministry of Agriculture and Forestry in Finland. The aims of the project were to clarify: 1) *aqua regia* extractable trace elements in Finnish cultivated soils with an international standard method at a national level; 2) *aqua regia* and AAAc-EDTA extractable trace elements in the top- and subsoil of Finnish arable land at selected crop and dairy farms; and 3) field mass balances of trace elements on the selected crop and dairy farms at the farm level.

The soil samples studied here were collected from 338 cultivated fields during the Finnish monitoring programme in 1998. The sampling sites were situated evenly on arable land all over the cultivated area in Finland: 7.7% being in the first and southernmost plant cultivation zone (I); 19.5% in the second (II); 44.1% in the third (III); 22.8% in the fourth (IV) and 5.9% in the fifth (V) zone. Of the soils studied, 65% were classified to coarse mineral soils, 15% to clay soils (clay content >30%) and 20% to organic soils (organic matter content >20%). The pH values of the fields are presented, too. The soil samples were analysed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, and zinc by using *aqua regia* extraction according to the international standard method (ISO 11466).

Medians and 90 percentile ranges (between 5% and 95%) of the trace element contents measured here were for Cd 0.15 (0.05-0.42), Cr 23 (7-67), Cu 17 (5-51), Pb 9 (4-18), Hg 0.04 (0.02-0.09), Ni 10 (4-34), Se 0.18 (0.08-0.71), V 32 (11-85) and Zn 43 (14-133) mg kg^{-1} dm. Trace element concentrations greatly varied by the soil types and by the plant cultivation zones. Often, the concentrations were low in the coarse mineral soils while the highest concentrations occurred in the clay soils. However, the highest concentrations of cadmium, mercury and selenium were measured in the organic soils. Contents of cadmium and lead were higher in the south than in the north because of the high population density, intensive industry and traffic and their emissions in southern Finland. Regional differences in the trace element concentrations were also partly due to the differences in the soil types. Concentrations of arsenic, copper and nickel in Finnish cultivated soils geographically seemed to reflect the respective concentrations measured in glacial till. Statistical indicators of the trace elements are presented by soil type groups and by plant cultivation zones. The distribution of the trace elements into the concentration classes are shown graphically on histograms and geographical distributions on the thematic maps.

Mean trace element contents increased in the soil material: Hg < Cd < Se < As < Pb < Ni < Cu < Cr < V < Zn. The Finnish arable land seemed to contain more Se, Cu and Zn than the Earth's crust, on average. Mean trace element contents of the Finnish cultivated soils were at the same level as in other Nordic countries. However, the contents were low when compared internationally, particularly with the contents of Cd and Pb.

Majority of the Cd, Hg and Pb contents measured here exceeded the natural Finnish soil background contents measured in fine-grained glacial till. Obviously, the main reasons for the accumulation of these trace elements were the earlier anthropogenic inputs into the soil from the atmosphere (Pb), P-fertilizers (Cd) and pesticides (Hg), respectively. In addition, about 10% of Zn contents and some cases of V contents were higher than the Finnish natural values.

All the Finnish Cd, Pb and Hg contents were lower than the respective Canadian limit values for agricultural soils. However, 7% of Cr contents, 3% of Se contents, 2% of As and Cu contents and about 1% of V and Zn contents exceeded the respective Canadian limit values.

When the trace element contents were compared to the "Clean Soil" values proposed for the Finnish cultivated soils, about 95% of As, Cr and Pb contents, 75-80% of Cd, Cu, Ni and Zn contents, but only a few cases of Hg contents could be classified as a clean soil.

This study was the first nationwide survey on *aqua regia* extractable trace elements in Finnish cultivated soils. The survey consisted of a relatively large number of sampling sites and trace elements that were determined using an international standard method. This study gives an opportunity to compare the trace element contents of the Finnish arable soils directly with the respective international and other national values. Although trace element contents obtained here were, in general, low, there were also a number of soils with elevated contents. This nationwide trace element survey forms a fundamental basis for the monitoring programme on Finnish arable land. To recognize and manage health and ecological risks, it is important to follow up the trace element trends in cultivated soils in the coming years.

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8 Appendixes

Appendix 1

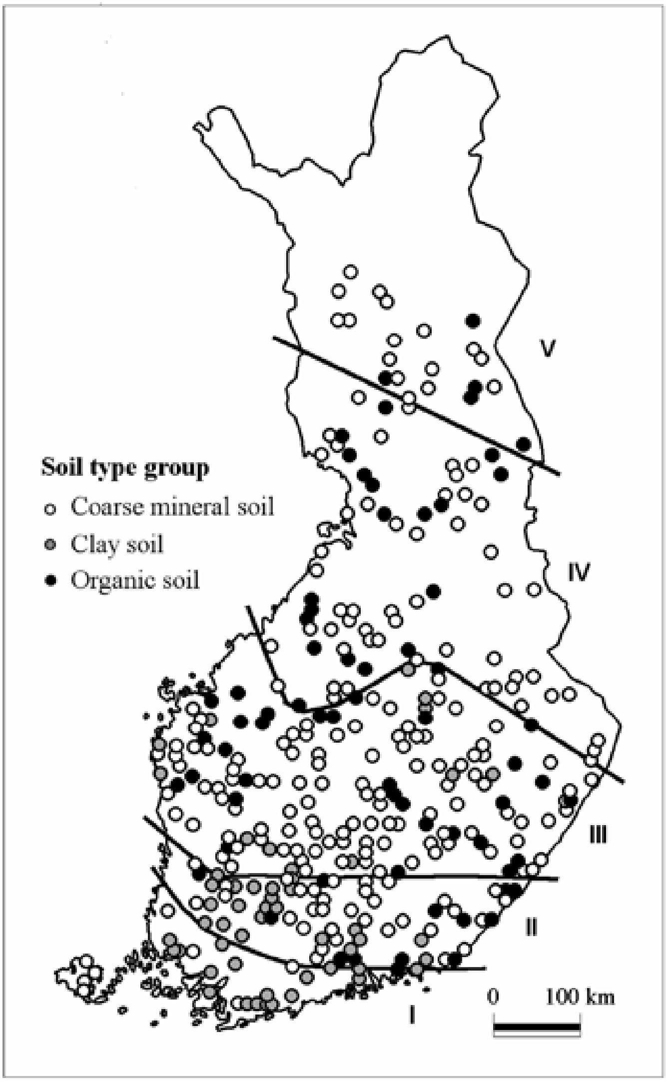

Figure 1. Sites (n = 338) of cultivated Finnish fields sampled in the national soil monitoring in 1998 and analyzed for trace elements in this study. Plant cultivation zones (I-V) of Finland.

Table 1. Statistical indicators of humus contents (% in dm) by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Humus	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	2.1	2.8	4.1	5.1	7.3	14	20	6.3	3.5	219
Clay soils	2.0	2.4	3.9	5.4	6.8	10	14	5.6	2.5	51
Organic soils*	20	21	31	45	61	79	83	47	20	68
All together	2.0	2.9	4.3	5.9	12	61	83	14	19	338

*One case <20% in cultivation zones of II (13% in dm), III (3.4% in dm) and IV (12 % in dm)

Table 2. Statistical indicators of humus contents (% in dm) by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Humus		Cultivation zone					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	4.6	4.9	5.2	4.9	6.5	5.1
	Mean	6.6	6.5	6.2	6.2	6.7	6.3
	Std	5.0	3.5	3.2	3.7	3.5	3.5
	Min	2.7	2.8	2.1	2.2	2.8	2.1
	Max	18	15	18	20	14	20
Clay soils	n	17	21	13			51
	Median	5.0	4.7	7.0			5.4
	Mean	5.6	4.9	6.9			5.6
	Std	2.8	1.8	2.8			2.5
	Min	2.7	2.2	2.0			2.0
	Max	14	10	11			14
Organic soils	n	1	11	30	21	5	68
	Median	66	30	42	56	75	45
	Mean	66	32	43	55	69	47
	Std		9.8	18	21	18	20
	Min*	66	13	3.4	12	37	3.4
	Max	66	45	76	83	81	83
All together	n	26	66	149	77	20	338
	Median	5.0	5.4	6.4	6.1	7.6	5.9
	Mean	8.2	10	14	20	22	14
	Std	12	11	17	25	29	19
	Min	2.7	2.2	2.0	2.2	2.8	2.0
	Max	66	45	76	83	81	83

*One case <20% in cultivation zones of II (12.8% in dm), III (3.4% in dm) and IV (12.1% in dm)

Table 3. Statistical indicators of pH(H_20) by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

pH	Statistical indicators									
Soil type roup	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	4.7	5.1	5.5	5.9	6.2	6.7	7.0	5.9	0.5	219
Clay soils	4.8	5.3	5.7	6.0	6.4	6.7	7.3	6.0	0.5	51
Organic soils	3.9	4.4	5.0	5.2	5.5	6.0	6.4	5.2	0.5	68
All together	3.9	4.9	5.4	5.8	6.2	6.7	7.3	5.8	0.6	338

Table 4. Statistical indicators of pH(H_20) by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

pH		Cultivation zone					Average
Soil type type		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	6.4	5.8	5.9	5.9	5.4	5.9
	Mean	6.3	5.9	6.0	5.8	5.5	5.9
	Std	0.6	0.5	0.4	0.5	0.5	0.5
	Min	5.5	5.0	5.0	4.7	4.8	4.7
	Max	7.0	7.0	7.0	6.8	6.4	7.0
Clay soils	n	17	21	13			51
	Median	6.2	6.0	6.0			6.0
	Mean	6.1	6.0	6.0			6.0
	Std	0.6	0.4	0.5			0.5
	Min	4.8	5.2	5.2			4.8
	Max	7.3	6.7	7.1			7.3
Organic soils	n	1	11	30	21	5	68
	Median	5.4	5.3	5.2	5.1	4.7	5.2
	Mean	5.4	5.4	5.3	5.1	4.9	5.2
	Std		0.3	0.5	0.5	0.6	0.5
	Min	5.4	5.0	3.9	4.3	4.4	3.9
	Max	5.4	6.0	6.4	6.4	5.9	6.4
All together	n	26	66	149	77	20	338
	Median	6.3	5.8	5.8	5.6	5.3	5.8
	Mean	6.1	5.8	5.8	5.6	5.4	5.8
	Std	0.6	0.5	0.5	0.6	0.6	0.6
	Min	4.8	5.0	3.9	4.3	4.4	3.9
	Max	7.3	7.0	7.1	6.8	6.4	7.3

Table 5. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of arsenic by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

As	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	0.32	0.72	1.56	2.40	3.58	6.92	166	3.61	11.2	219
Clay soils	1.98	2.35	5.74	7.79	9.12	12.2	17.9	7.51	3.16	51
Organic soils	0.69	0.99	1.93	2.53	3.60	9.05	16.8	3.30	2.66	68
All together	0.32	0.88	1.79	2.76	4.59	9.42	166	4.13	9.28	338

Table 6. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of arsenic by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

As		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	3.84	3.53	2.34	1.53	1.80	2.40
	Mean	4.05	8.80	2.81	2.02	3.14	3.61
	Std	1.76	27.8	1.79	1.39	3.64	11.2
	Min	1.35	1.79	0.73	0.32	0.38	0.32
	Max	6.98	166	10.6	5.59	14.6	166
Clay soils	n	17	21	13			51
	Median	8.10	8.55	5.14			7.79
	Mean	8.56	8.20	5.02			7.51
	Std	3.04	2.99	2.30			3.16
	Min	5.48	2.04	1.98			1.98
	Max	17.9	14.6	7.88			17.9
Organic soils	n	1	11	30	21	5	68
	Median	8.89	2.83	3.13	2.17	1.01	2.53
	Mean	8.89	4.06	3.71	2.53	1.24	3.30
	Std		2.83	3.14	1.19	0.64	2.66
	Min	8.89	1.19	0.79	1.00	0.69	0.69
	Max	8.89	9.42	16.8	5.59	2.29	16.8
All together	n	26	66	149	77	20	338
	Median	6.79	4.54	2.48	1.99	1.55	2.76
	Mean	7.18	7.82	3.18	2.16	2.67	4.13
	Std	3.37	20.0	2.26	1.35	3.25	9.28
	Min	1.35	1.19	0.73	0.32	0.38	0.32
	Max	17.9	166	16.8	5.59	14.6	166

Table 7. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of cadmium by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Cd	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	0.016	0.042	0.079	0.116	0.177	0.309	0.641	0.138	0.088	219
Clay soils	0.085	0.105	0.156	0.196	0.249	0.441	0.624	0.222	0.107	51
Organic soils	0.073	0.127	0.211	0.289	0.372	0.509	0.748	0.298	0.130	68
All together	0.016	0.047	0.096	0.153	0.231	0.416	0.748	0.183	0.120	338

Table 8. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of cadmium by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Cd		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	0.256	0.177	0.135	0.088	0.050	0.116
	Mean	0.246	0.219	0.140	0.092	0.056	0.138
	Std	0.112	0.127	0.064	0.045	0.024	0.088
	Min	0.084	0.065	0.040	0.016	0.021	0.016
	Max	0.435	0.641	0.347	0.242	0.105	0.641
Clay soils	n	17	21	13			51
	Median	0.195	0.191	0.210			0.196
	Mean	0.236	0.209	0.225			0.222
	Std	0.127	0.113	0.065			0.107
	Min	0.104	0.089	0.085			0.085
	Max	0.624	0.519	0.309			0.624
Organic soils	n	1	11	30	21	5	68
	Median	0.748	0.360	0.308	0.225	0.327	0.289
	Mean	0.748	0.371	0.298	0.245	0.270	0.298
	Std		0.161	0.101	0.094	0.139	0.130
	Min	0.748	0.101	0.129	0.073	0.101	0.073
	Max	0.748	0.656	0.510	0.469	0.397	0.748
All together	n	26	66	149	77	20	338
	Median	0.212	0.196	0.157	0.099	0.063	0.153
	Mean	0.259	0.241	0.179	0.134	0.109	0.183
	Std	0.154	0.140	0.097	0.092	0.116	0.120
	Min	0.084	0.065	0.040	0.016	0.021	0.016
	Max	0.748	0.656	0.510	0.469	0.397	0.748

Table 9. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of chromium by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Cr	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	2.3	7.9	13.0	20.1	34.0	59.2	92.5	25.7	16.7	219
Clay soils	23.9	33.4	47.4	54.8	65.6	88.0	93.2	57.2	15.9	51
Organic soils	1.6	4.2	9.6	15.8	26.7	46.6	59.4	20.3	14.1	68
All together	1.6	7.1	13.7	22.5	42.4	66.6	93.2	29.4	20.0	338

Table 10. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of chromium by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Cr		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	25.7	29.3	18.2	17.1	37.3	20.1
	Mean	24.2	34.2	21.2	24.3	45.1	25.7
	Std	11.3	18.5	11.4	17.9	22.1	16.7
	Min	7.1	9.2	2.3	4.7	21.7	2.3
	Max	43.2	65.2	56.1	74.5	92.5	92.5
Clay soils	n	17	21	13			51
	Median	58.6	60.1	50.7			54.8
	Mean	57.0	62.6	48.8			57.2
	Std	16.4	17.2	8.5			15.9
	Min	29.4	32.4	23.9			23.9
	Max	89.3	93.2	56.7			93.2
Organic soils	n	1	11	30	21	5	68
	Median	10.6	40.1	17.2	13.9	10.3	15.8
	Mean	10.6	36.9	19.3	15.7	10.8	20.3
	Std		19.0	9.8	11.8	3.0	14.1
	Min	10.6	9.5	4.1	1.6	6.5	1.6
	Max	10.6	59.4	39.4	44.5	14.0	59.4
All together	n	26	66	149	77	20	338
	Median	43.1	44.7	18.9	16.5	30.2	22.5
	Mean	45.1	43.7	23.2	22.0	36.5	29.4
	Std	22.2	22.2	13.4	16.8	24.4	20.0
	Min	7.1	9.2	2.3	1.6	6.5	1.6
	Max	89.3	93.2	56.7	74.5	92.5	93.2

Table 11. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of copper by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Cu	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	2.7	4.4	8.6	13.3	19.3	31.9	81.8	15.2	9.5	219
Clay soils	7.4	15.1	22.8	28.1	35.5	54.1	60.9	30.6	11.6	51
Organic soils	4.5	5.7	18.4	27.5	45.6	80.0	91.6	33.4	21.7	68
All together	2.7	5.3	10.3	17.1	27.3	51.2	91.6	21.2	15.5	338

Table 12. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of copper by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Cu		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	21.6	15.9	12.2	13.2	12.6	13.3
	Mean	20.1	18.8	13.5	14.0	21.4	15.2
	Std	7.0	10.3	7.3	7.9	19.6	9.5
	Min	8.7	5.8	2.7	3.2	4.2	2.7
	Max	28.6	46.5	47.4	34.6	81.8	81.8
Clay soils	n	17	21	13			51
	Median	27.4	32.4	28.1			28.1
	Mean	28.9	33.9	27.3			30.6
	Std	10.2	13.8	7.9			11.6
	Min	11.8	14.8	7.4			7.4
	Max	51.0	60.9	35.8			60.9
Organic soils	n	1	11	30	21	5	68
	Median	49.9	32.1	26.0	32.1	26.7	27.5
	Mean	49.9	34.9	29.5	38.4	29.7	33.4
	Std		22.4	14.9	29.1	20.8	21.7
	Min	49.9	5.5	9.2	4.5	5.4	4.5
	Max	49.9	74.7	74.6	91.6	53.0	91.6
All together	n	26	66	149	77	20	338
	Median	25.3	22.9	14.9	15.1	14.6	17.1
	Mean	27.0	26.3	17.9	20.7	23.5	21.2
	Std	10.9	15.9	11.6	19.7	19.7	15.5
	Min	8.7	5.5	2.7	3.2	4.2	2.7
	Max	51.0	74.7	74.6	91.6	81.8	91.6

Table 13. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of lead by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Pb	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	2.1	4.3	6.2	7.6	9.7	13.4	57.9	8.3	4.5	219
Clay soils	6.6	8.9	12.7	15.6	17.9	21.5	23.0	15.4	3.9	51
Organic soils	3.5	4.3	7.4	9.0	11.2	17.2	21.4	9.7	3.7	68
All together	2.1	4.3	6.6	8.6	11.2	17.9	57.9	9.7	4.9	338

Table 14. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of lead by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Pb		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	10.2	9.8	7.6	6.9	5.1	7.6
	Mean	10.9	10.1	8.1	8.1	6.0	8.3
	Std	3.9	2.7	3.0	7.2	2.0	4.5
	Min	4.7	6.1	3.7	2.1	3.7	2.1
	Max	16.7	15.6	28.6	57.9	9.9	57.9
Clay soils	n	17	21	13			51
	Median	16.9	15.9	13.1			15.6
	Mean	17.2	15.4	12.9			15.4
	Std	3.8	3.8	3.0			3.9
	Min	10.9	8.7	6.6			6.6
	Max	23.0	22.1	18.6			23.0
Organic soils	n	1	11	30	21	5	68
	Median	18.6	11.8	8.6	9.5	6.5	9.0
	Mean	18.6	13.1	8.9	9.4	6.1	9.7
	Std		5.2	2.7	2.8	1.1	3.7
	Min	18.6	6.9	3.5	3.5	4.6	3.5
	Max	18.6	21.4	16.7	14.5	7.4	21.4
All together	n	26	66	149	77	20	338
	Median	16.3	11.1	8.0	7.6	5.4	8.6
	Mean	15.3	12.3	8.6	8.4	6.0	9.7
	Std	4.8	4.2	3.2	6.4	1.8	4.9
	Min	4.7	6.1	3.5	2.1	3.7	2.1
	Max	23.0	22.1	28.6	57.9	9.9	57.9

Table 15. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of mercury by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Hg	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	0.008	0.016	0.025	0.033	0.044	0.063	0.949	0.040	0.063	219
Clay soils	0.014	0.022	0.035	0.041	0.055	0.072	0.091	0.045	0.017	51
Organic soils	0.011	0.032	0.052	0.068	0.087	0.129	0.143	0.072	0.029	68
All together	0.008	0.017	0.028	0.039	0.055	0.089	0.949	0.047	0.055	338

Table 16. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of mercury by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Hg		Plant cultivation zone					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	0.044	0.038	0.038	0.027	0.025	0.033
	Mean	0.043	0.069	0.039	0.028	0.025	0.040
	Std	0.012	0.157	0.013	0.010	0.006	0.063
	Min	0.025	0.014	0.011	0.008	0.016	0.008
	Max	0.056	0.949	0.076	0.060	0.036	0.949
Clay soils	n	17	21	13			51
	Median	0.054	0.039	0.037			0.041
	Mean	0.054	0.041	0.039			0.045
	Std	0.017	0.015	0.015			0.017
	Min	0.031	0.015	0.014			0.014
	Max	0.091	0.071	0.066			0.091
Organic soils	n	1	11	30	21	5	68
	Median	0.089	0.064	0.081	0.062	0.055	0.068
	Mean	0.089	0.068	0.081	0.067	0.047	0.072
	Std		0.027	0.033	0.023	0.019	0.029
	Min	0.089	0.034	0.011	0.031	0.020	0.011
	Max	0.089	0.115	0.143	0.115	0.066	0.143
All together	n	26	66	149	77	20	338
	Median	0.051	0.042	0.040	0.029	0.025	0.039
	Mean	0.052	0.060	0.047	0.038	0.030	0.047
	Std	0.018	0.113	0.026	0.023	0.014	0.055
	Min	0.025	0.014	0.011	0.008	0.016	0.008
	Max	0.091	0.949	0.143	0.115	0.066	0.949

Table 17. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of nickel by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Ni	Statistical indicators									
Soil type group	Min	5 %	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	1.2	3.2	5.4	8.6	15.2	27.9	45.3	11.4	8.1	219
Clay soils	7.7	14.7	21.0	27.3	33.6	44.2	46.4	28.0	9.1	51
Organic soils	1.6	4.4	6.2	8.5	15.3	26.8	33.5	10.9	7.0	68
All together	1.2	3.6	5.9	10.0	18.9	33.6	46.4	13.8	10.0	338

Table 18. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of nickel by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Ni		Plant cultivation zone					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	14.1	13.8	7.5	6.5	13.6	8.6
	Mean	13.3	16.0	9.6	10.4	16.1	11.4
	Std	7.3	8.8	6.4	9.3	8.8	8.1
	Min	3.6	5.3	1.2	1.9	5.1	1.2
	Max	25.6	31.5	45.3	36.4	29.0	45.3
Clay soils	n	17	21	13			51
	Median	25.6	29.3	27.3			27.3
	Mean	25.8	30.8	26.2			28.0
	Std	8.7	10.1	7.0			9.1
	Min	13.1	12.7	7.7			7.7
	Max	46.3	46.4	35.8			46.4
Organic soils	n	1	11	30	21	5	68
	Median	6.9	20.4	9.1	7.3	8.0	8.5
	Mean	6.9	18.6	11.0	7.7	7.6	10.9
	Std		10.7	5.7	3.8	2.4	7.0
	Min	6.9	4.6	4.7	1.6	4.2	1.6
	Max	6.9	33.5	30.7	17.9	10.0	33.5
All together	n	26	66	149	77	20	338
	Median	19.8	20.9	8.9	6.6	10.1	10.0
	Mean	21.2	21.1	11.4	9.7	13.9	13.8
	Std	10.3	11.5	7.8	8.2	8.5	10.0
	Min	3.6	4.6	1.2	1.6	4.2	1.2
	Max	46.3	46.4	45.3	36.4	29.0	46.4

Table 19. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of selenium by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Se	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	0.030	0.070	0.110	0.150	0.210	0.340	2.330	0.180	0.173	219
Clay soils	0.100	0.120	0.190	0.250	0.320	0.550	0.910	0.278	0.149	51
Organic soils	0.070	0.170	0.330	0.465	0.635	1.169	5.440	0.632	0.771	68
All together	0.030	0.080	0.130	0.180	0.300	0.712	5.440	0.286	0.415	338

Table 20. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of selenium by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Se		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	0.185	0.180	0.150	0.130	0.130	0.150
	Mean	0.193	0.269	0.177	0.137	0.163	0.180
	Std	0.064	0.381	0.098	0.066	0.089	0.173
	Min	0.110	0.070	0.050	0.030	0.080	0.030
	Max	0.310	2.330	0.710	0.310	0.400	2.330
Clay soils	n	17	21	13			51
	Median	0.270	0.250	0.210			0.250
	Mean	0.282	0.305	0.227			0.278
	Std	0.112	0.190	0.104			0.149
	Min	0.130	0.110	0.100			0.100
	Max	0.590	0.910	0.390			0.910
Organic soils	n	1	11	30	21	5	68
	Median	1.110	0.530	0.470	0.380	0.600	0.465
	Mean	1.110	1.023	0.542	0.401	1.188	0.632
	Std		1.498	0.278	0.206	1.540	0.771
	Min	1.110	0.100	0.140	0.070	0.170	0.070
	Max	1.110	5.440	1.400	0.990	3.920	5.440
All together	n	26	66	149	77	20	338
	Median	0.245	0.220	0.180	0.140	0.140	0.180
	Mean	0.287	0.406	0.255	0.209	0.419	0.286
	Std	0.198	0.712	0.210	0.168	0.844	0.415
	Min	0.110	0.070	0.050	0.030	0.080	0.030
	Max	1.110	5.440	1.400	0.990	3.920	5.440

Table 21. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of vanadium by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

V	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	5.6	13.3	20.5	28.2	46.5	70.7	92.0	34.2	17.9	219
Clay soils	26.2	42.6	58.5	71.9	90.8	129	133	75.7	24.8	51
Organic soils	2.7	6.6	15.2	25.2	34.1	64.9	273	30.7	34.2	68
All together	2.7	10.6	20.6	31.9	53.3	85.3	273	39.7	27.6	338

Table 22. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of vanadium by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

V		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	31.1	36.2	26.4	25.1	51.0	28.2
	Mean	31.5	42.7	29.8	33.0	51.2	34.2
	Std	12.2	21.3	14.0	19.5	14.9	17.9
	Min	10.9	13.3	5.6	8.7	26.0	5.6
	Max	51.6	75.8	71.9	92.0	74.5	92.0
Clay soils	n	17	21	13			51
	Median	71.9	82.5	64.9			71.9
	Mean	74.3	83.5	64.9			75.7
	Std	22.3	26.0	23.0			24.8
	Min	41.7	33.2	26.2			26.2
	Max	128	133	130			133
Organic soils	n	1	11	30	21	5	68
	Median	29.5	45.2	29.1	18.3	14.5	25.2
	Mean	29.5	43.3	27.3	33.4	12.2	30.7
	Std		23.7	10.4	57.3	4.0	34.2
	Min	29.5	11.7	9.4	2.7	5.8	2.7
	Max	29.5	81.2	47.2	273	15.4	273
All together	n	26	66	149	77	20	338
	Median	55.9	55.3	28.1	24.3	41.7	31.9
	Mean	59.4	55.8	32.4	33.1	41.4	39.7
	Std	28.2	29.8	17.5	33.8	21.6	27.6
	Min	10.9	11.7	5.6	2.7	5.8	2.7
	Max	128	133	130	273	74.5	273

Table 23. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of zinc by soil type groups in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Mean = mean, Std = standard deviation, n = number of samples and % = percentiles.

Zn	Statistical indicators									
Soil type group	Min	5%	25%	50%	75%	95%	Max	Mean	Std	n
Coarse mineral soils	6.2	13.8	25.6	40.2	62.8	104	264	48.5	33.3	219
Clay soils	31.8	50.0	79.1	95.4	132	180	248	108	43.3	51
Organic soils	5.7	10.6	19.9	28.5	41.4	76.3	101	33.9	20.6	68
All together	5.7	13.8	26.0	42.6	72.7	133	264	54.5	40.2	338

Table 24. Statistical indicators of *aqua regia* extractable contents (mg kg^{-1} dm) of zinc by soil type groups and by cultivation zones (I-V) in Finnish cultivated fields sampled in the national soil monitoring in 1998. Min = minimum, Max = maximum, Std = standard deviation, n = number of samples.

Zn		Plant cultivation zone of Finland					Average
Soil type group		I	II	III	IV	V	
Coarse mineral soils	n	8	34	106	56	15	219
	Median	48.2	73.5	42.4	31.1	34.6	40.2
	Mean	56.3	77.8	47.5	35.8	33.6	48.5
	Std	35.1	41.8	31.9	21.0	12.9	33.3
	Min	18.6	19.6	6.2	8.1	17.9	6.2
	Max	130	174	264	95.6	54.3	264
Clay soils	n	17	21	13			51
	Median	88.2	132	85.0			95.4
	Mean	96.7	124	95.8			108
	Std	28.1	45.1	50.9			43.3
	Min	50.8	39.2	31.8			31.8
	Max	145	221	248			248
Organic soils	n	1	11	30	21	5	68
	Median	31.3	44.7	30.9	25.5	12.8	28.5
	Mean	31.3	46.9	35.0	30.8	12.4	33.9
	Std		23.1	17.2	22.4	4.7	20.6
	Min	31.3	14.3	15.7	6.4	5.7	5.7
	Max	31.3	89.7	101	91.6	18.3	101
All together	n	26	66	149	77	20	338
	Median	80.6	88.0	41.6	29.3	22.4	42.6
	Mean	81.7	87.2	49.2	34.4	28.3	54.5
	Std	36.2	48.5	35.0	21.4	14.7	40.2
	Min	18.6	14.3	6.2	6.4	5.7	5.7
	Max	145	221	264	95.6	54.3	264

Appendix 2

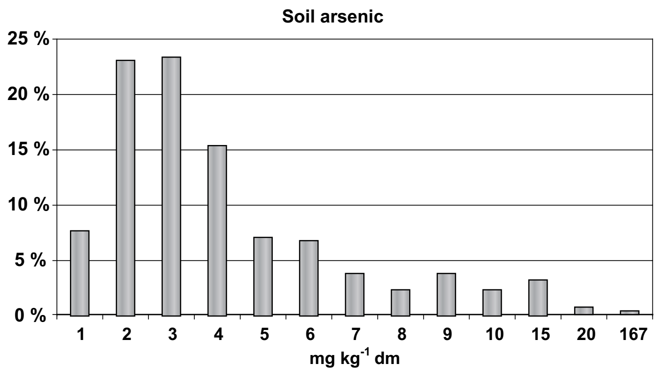

Figure 1. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of arsenic in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 20 mg kg^{-1} dm.

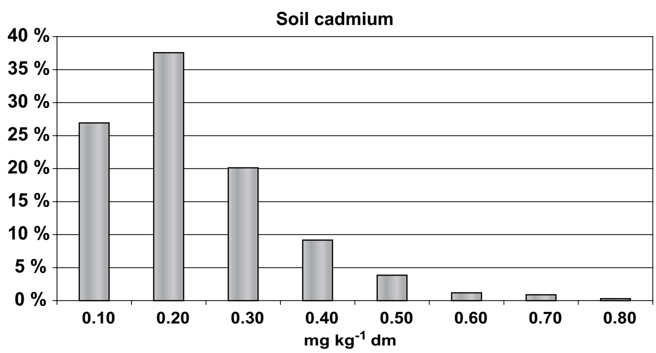

Figure 2. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of cadmium in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998.

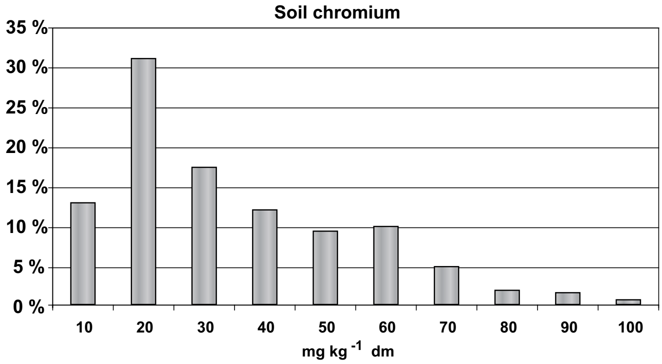

Figure 3. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of chromium in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998.

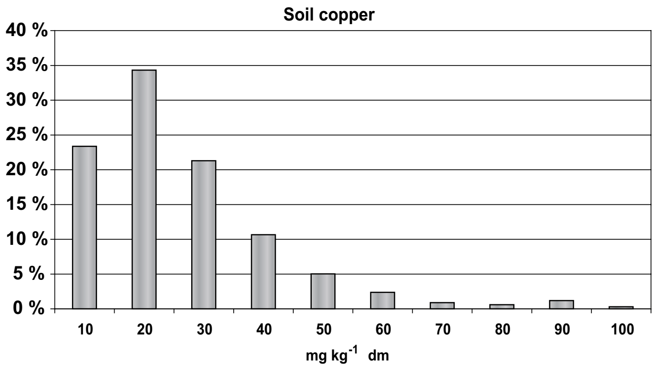

Figure 4. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of copper in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998.

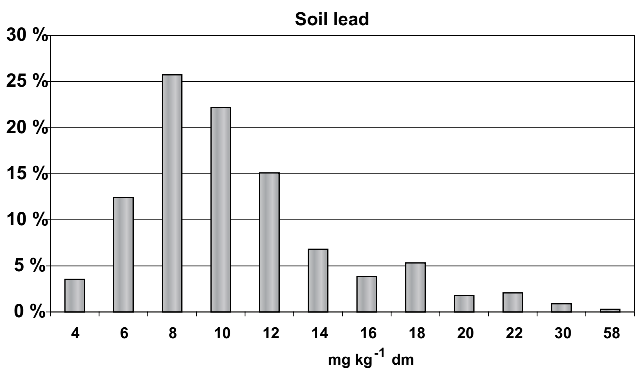

Figure 5. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of lead in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 22 mg kg^{-1} dm.

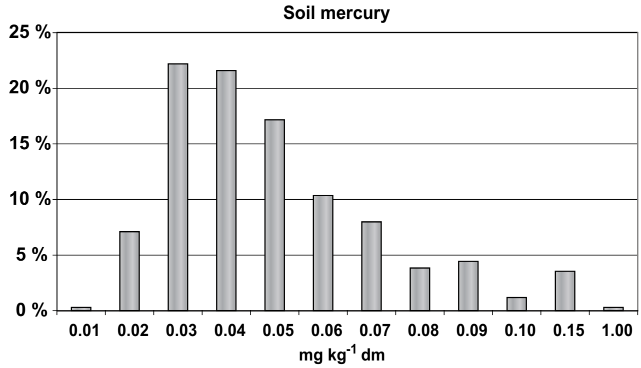

Figure 6. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of mercury in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 0.10 mg kg^{-1} dm.

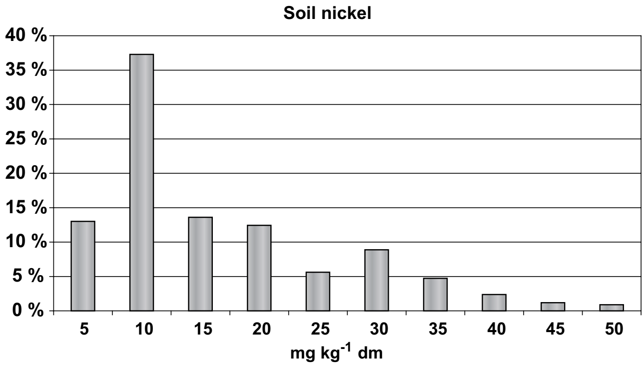

Figure 7. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of nickel in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998.

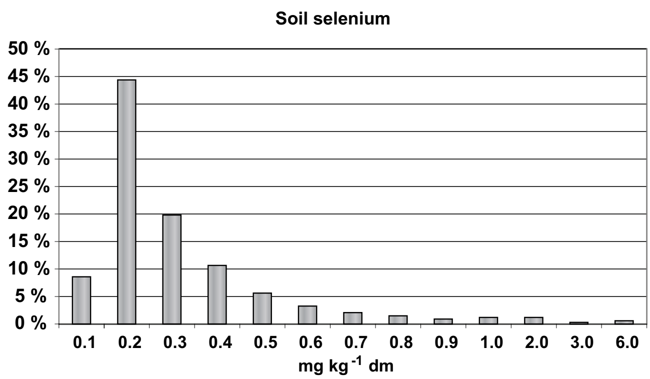

Figure 8. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of selenium in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 1.0 mg kg^{-1} dm.

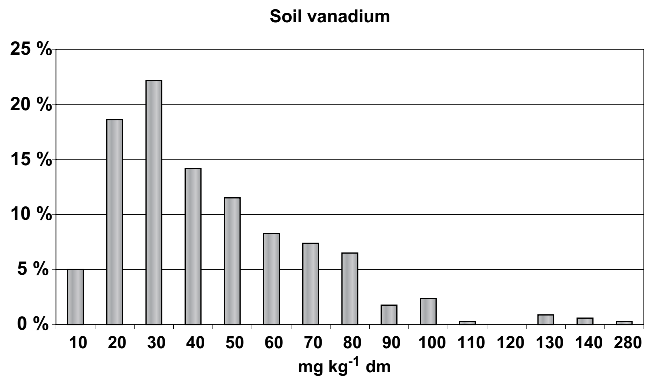

Figure 9. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of vanadium in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 140 mg kg^{-1} dm.

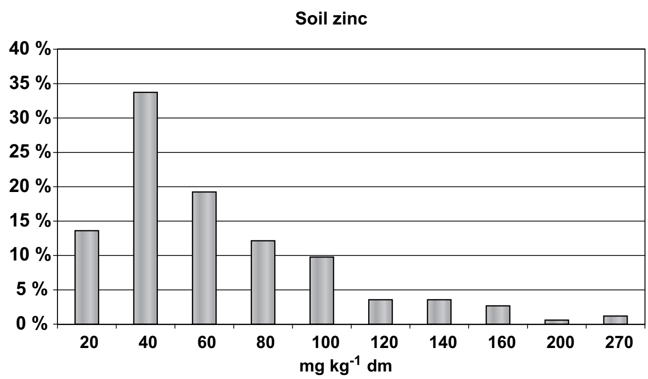

Figure 10. Distribution (%) of *aqua regia* extractable contents (mg kg^{-1} dm) of zinc in Finnish cultivated fields (n = 338) sampled in the national soil monitoring in 1998. Please note that the concentration scale is not linear after 160 mg kg^{-1} dm.

Appendix 3

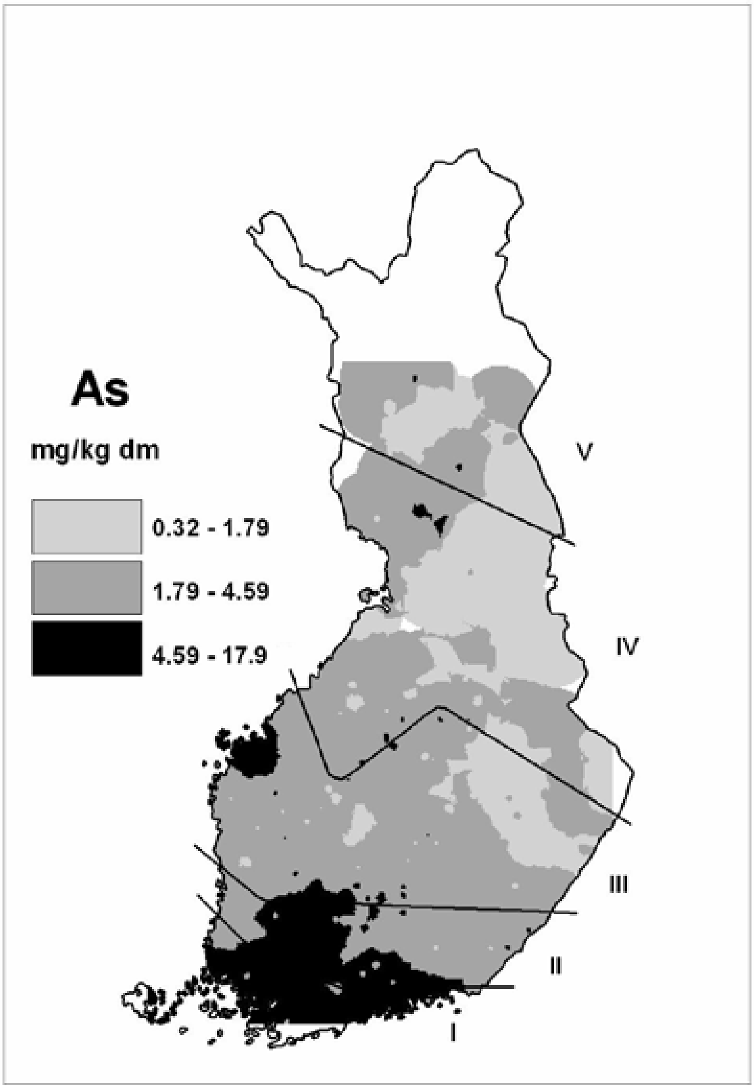

Figure 1. Spatial distribution of *aqua regia* extractable arsenic in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

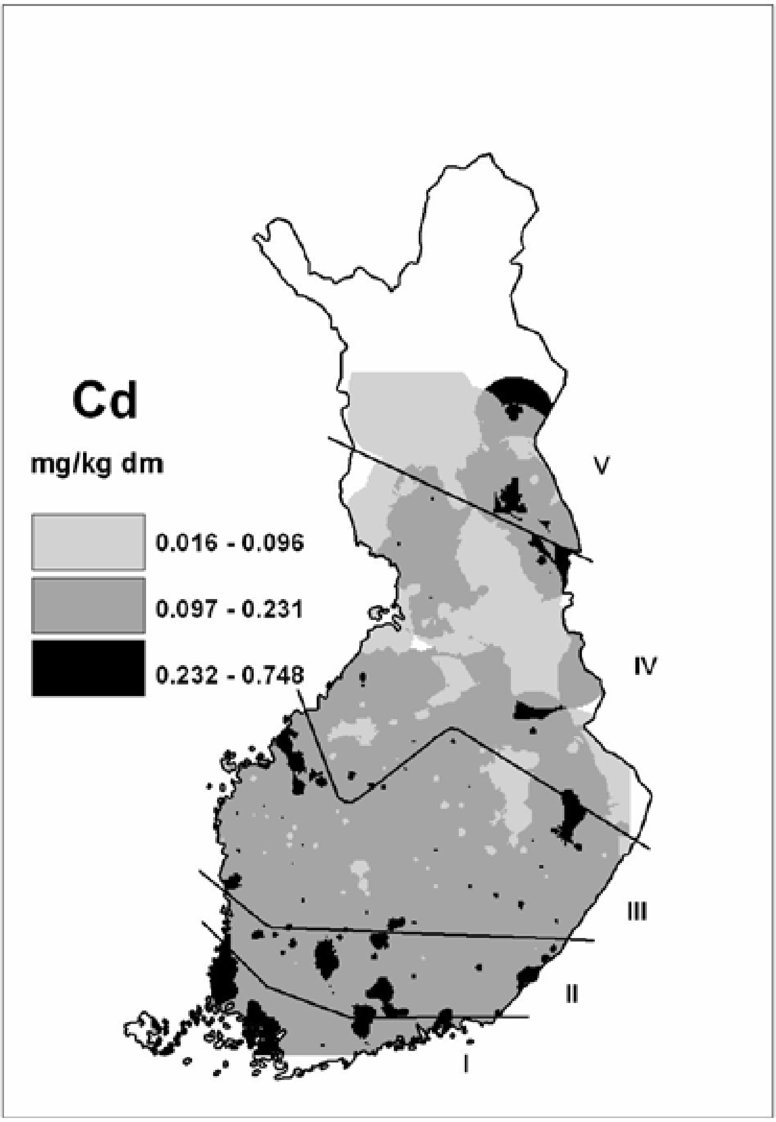

Figure 2. Spatial distribution of *aqua regia* extractable cadmium in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

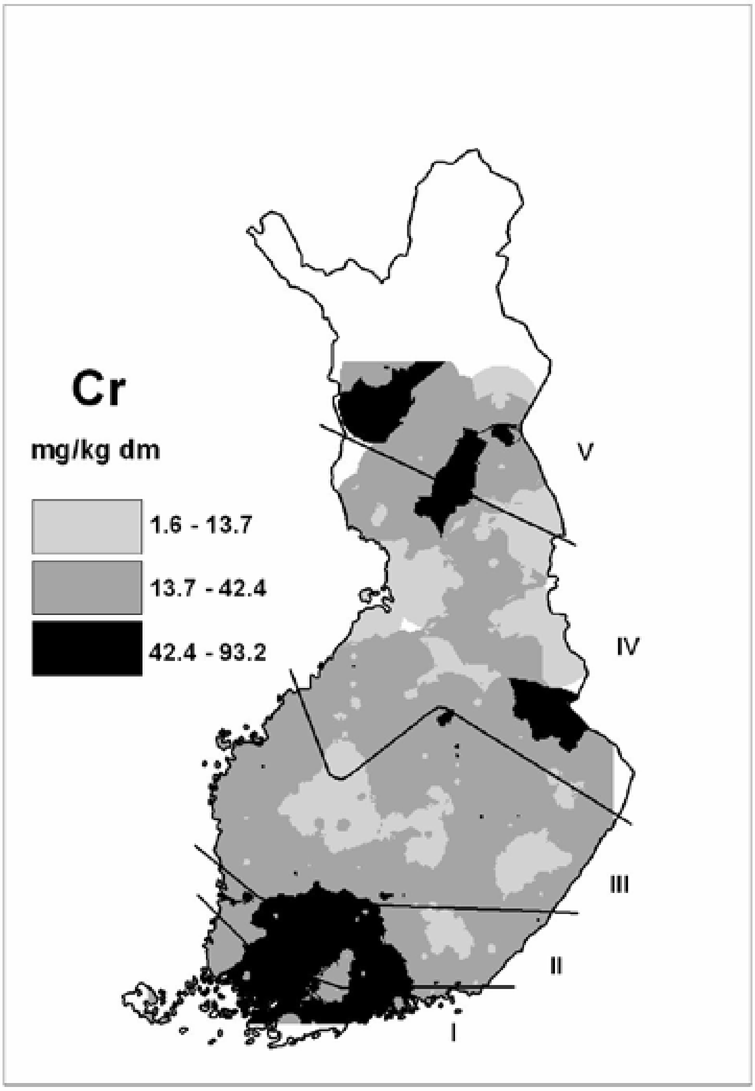

Figure 3. Spatial distribution of *aqua regia* extractable chromium in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

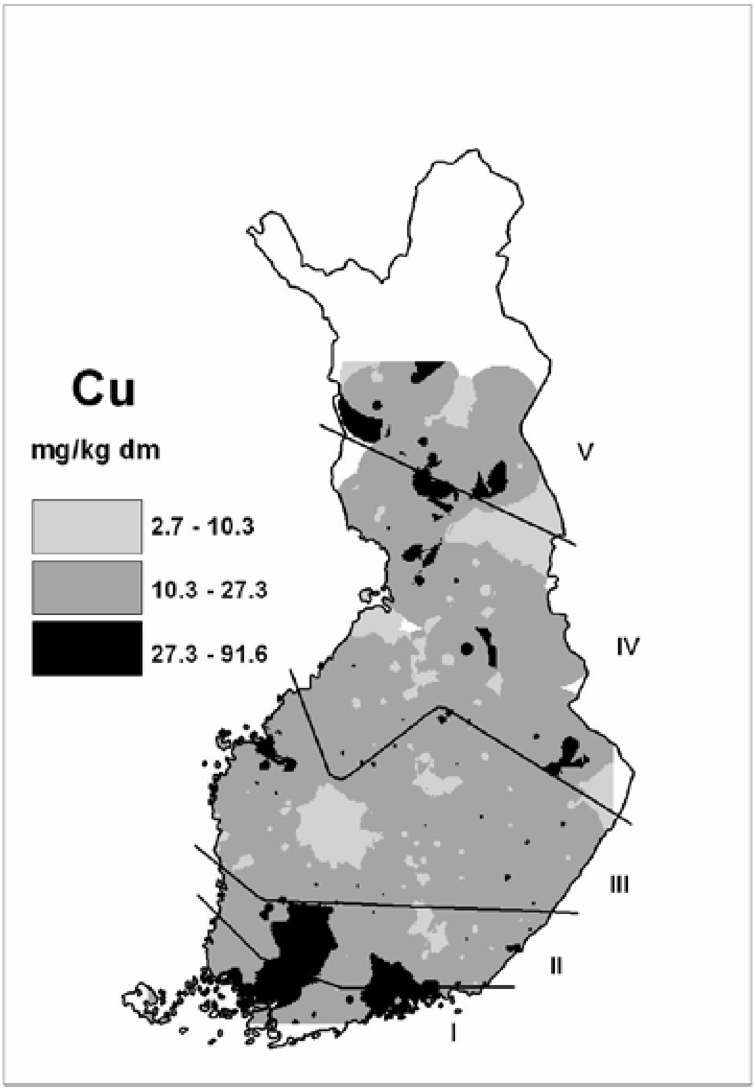

Figure 4. Spatial distribution of *aqua regia* extractable copper in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

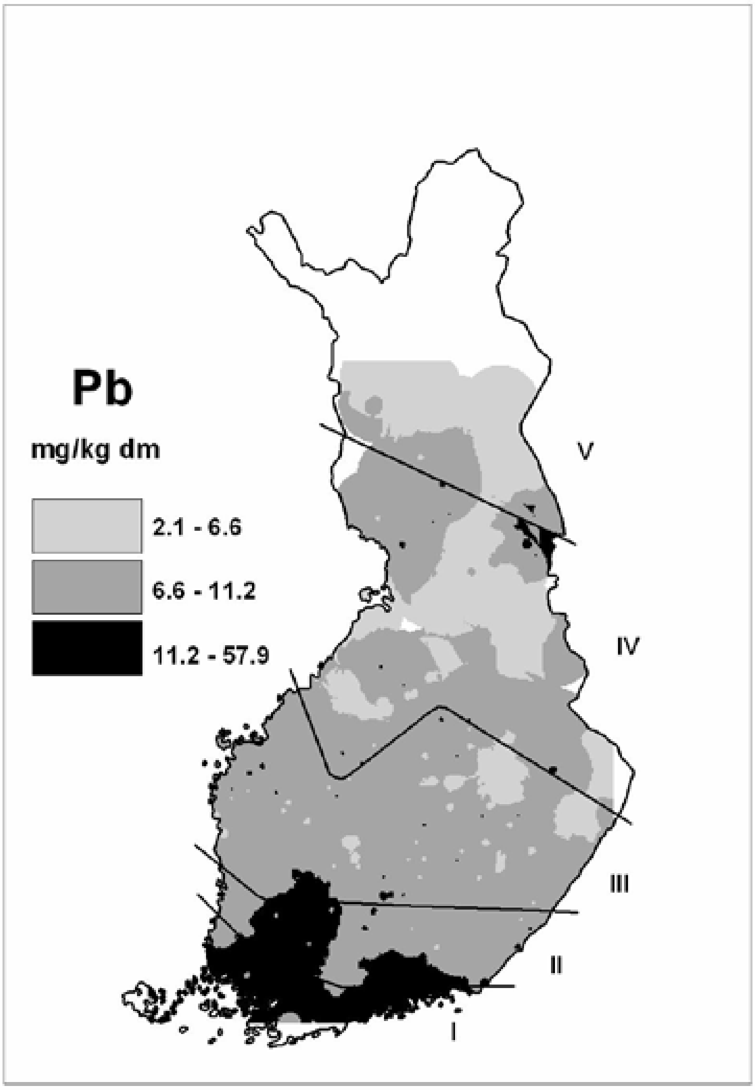

Figure 5. Spatial distribution of *aqua regia* extractable lead in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

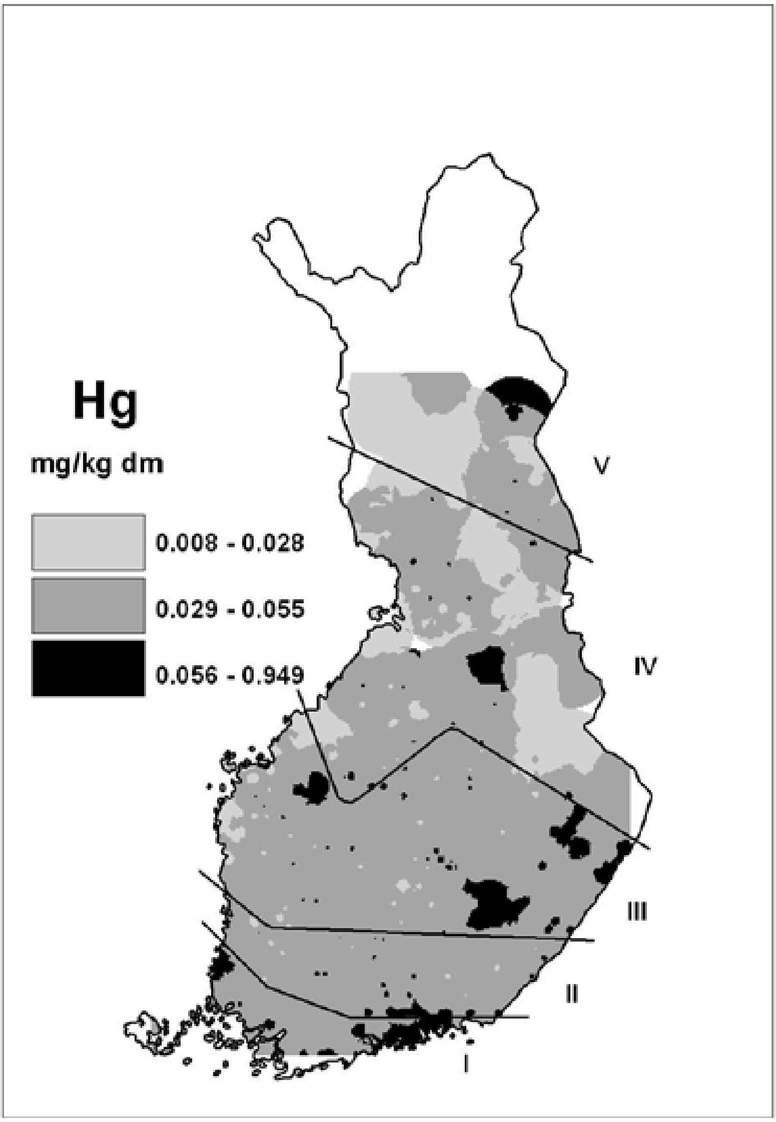

Figure 6. Spatial distribution of *aqua regia* extractable mercury in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

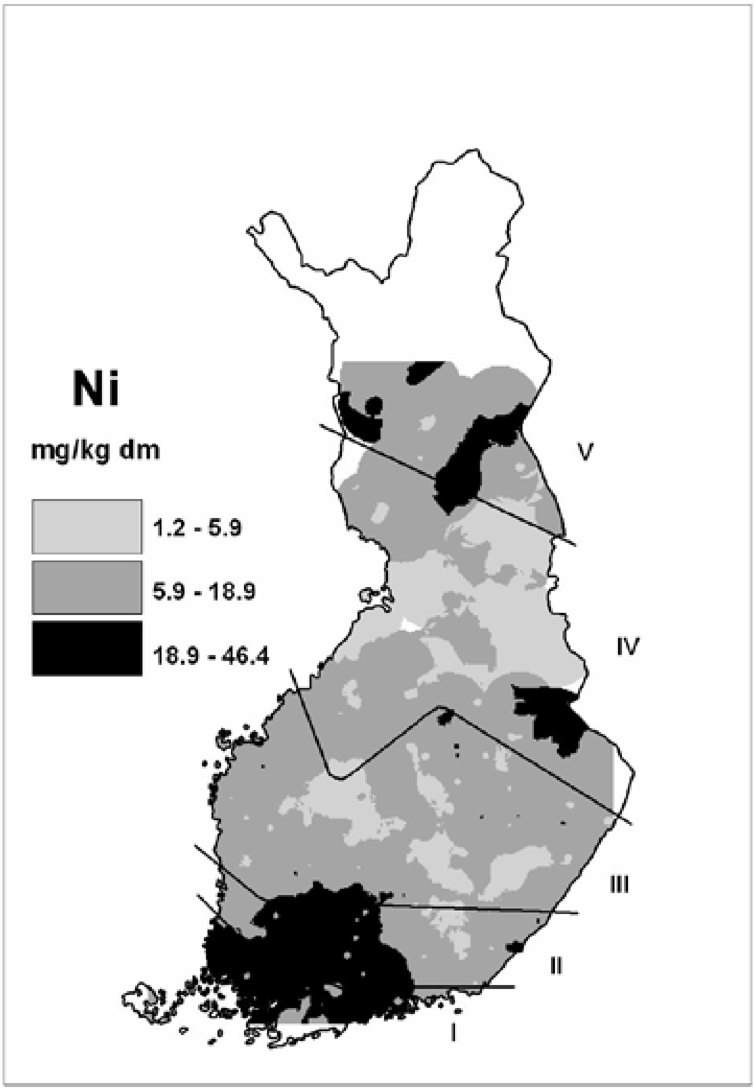

Figure 7. Spatial distribution of *aqua regia* extractable nickel in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

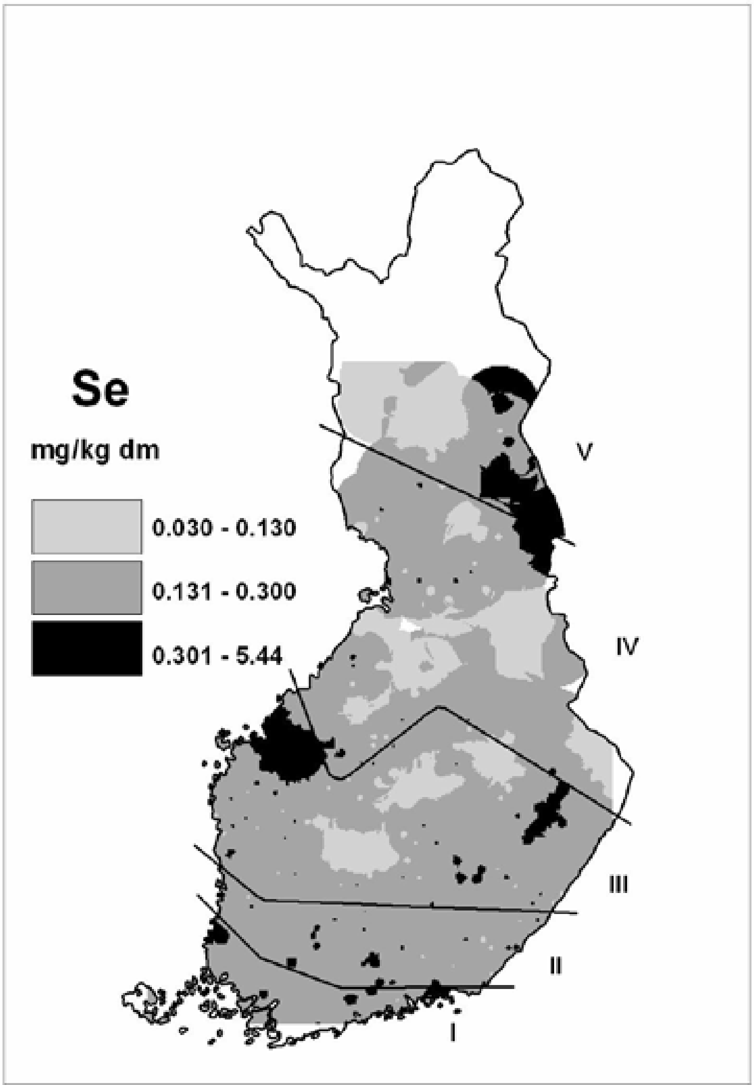

Figure 8. Spatial distribution of *aqua regia* extractable selenium in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

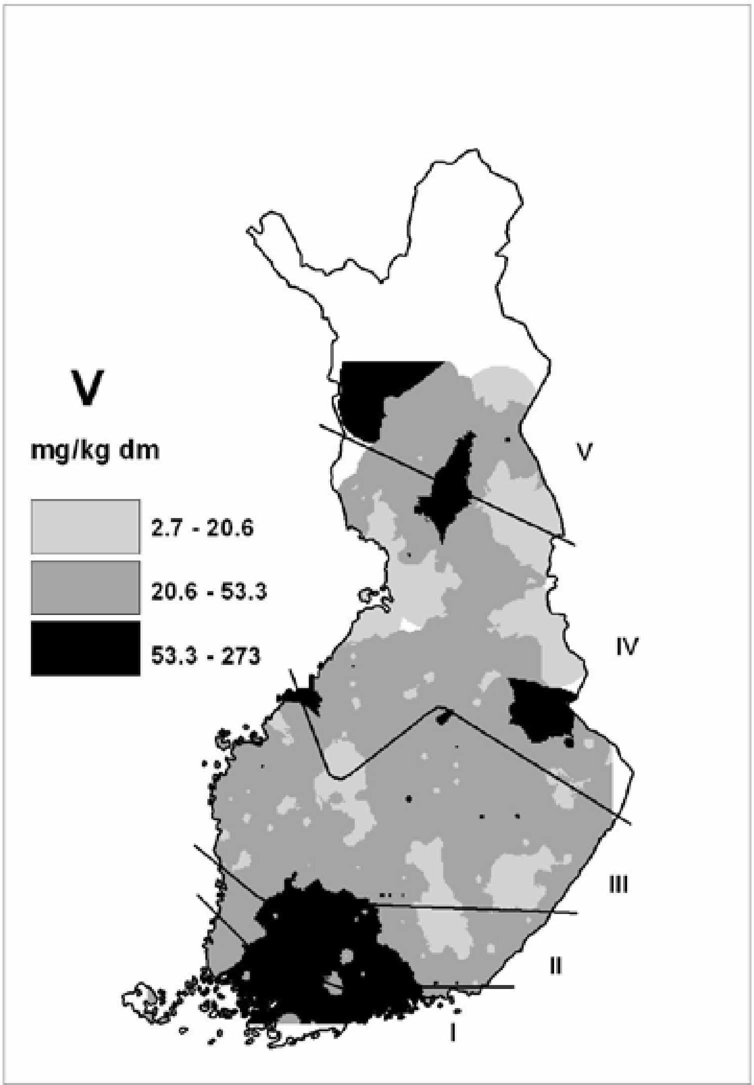

Figure 9. Spatial distribution of *aqua regia* extractable vanadium in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

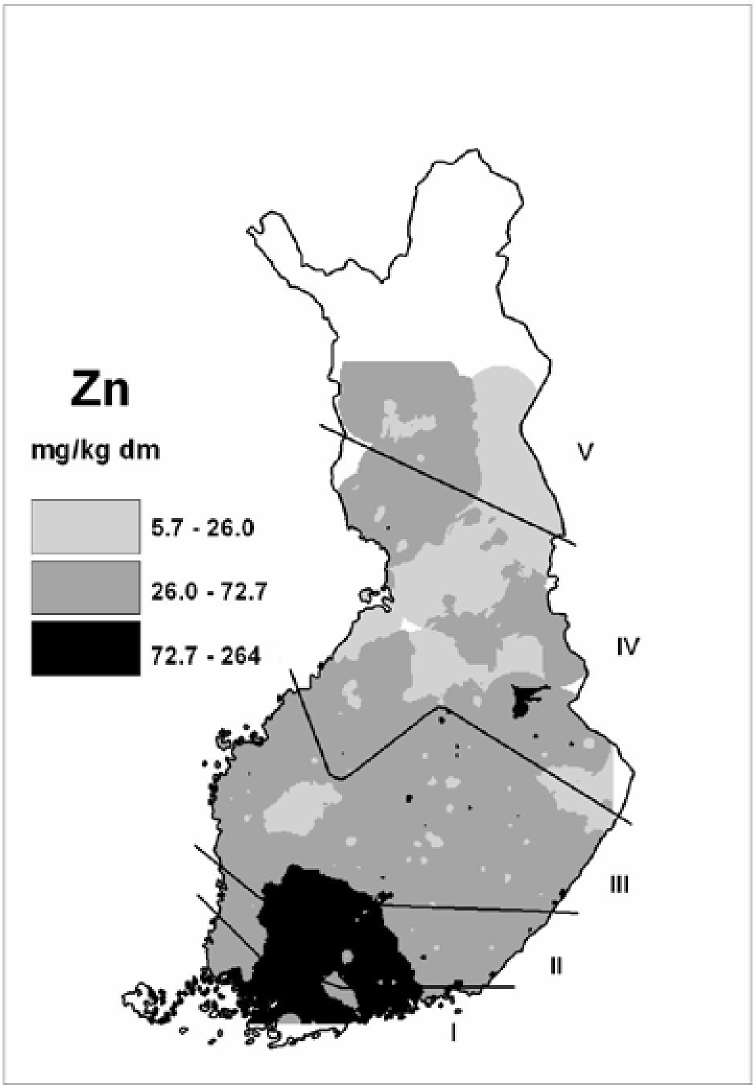

Figure 10. Spatial distribution of *aqua regia* extractable zinc in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998. Plant cultivation zones (I-V) of Finland.

Appendix 4

Table 1. Correlations of general soil characteristics and *aqua regia* extractable trace elements in Finnish cultivated soils (n = 338) sampled in the national soil monitoring in 1998.

	pH(H_2O)	Humus	Bulk density	El. cond.	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	V	Zn
pH(H_2O)	1.000													
Humus	-0.559	1.000												
Bulk density	0.561	-0.914	1.000											
El. cond.	0.009	0.044	-0.025	1.000										
As	0.026	-0.035	-0.028	0.006	1.000									
Cd	-0.066	0.370	-0.429	0.028	0.175	1.000								
Cr	0.157	-0.289	0.078	-0.071	0.266	0.207	1.000							
Cu	-0.107	0.416	-0.478	0.020	0.153	0.442	0.411	1.000						
Pb	0.057	0.004	-0.124	-0.025	0.161	0.353	0.486	0.374	1.000					
Hg	-0.047	0.241	-0.270	0.023	0.089	0.253	0.038	0.282	0.146	1.000				
Ni	0.120	-0.191	-0.027	-0.054	0.269	0.300	**0.950**	0.483	0.509	0.058	1.000			
Se	-0.221	0.422	-0.450	0.010	0.044	0.397	0.083	0.372	0.159	0.147	0.145	1.000		
V	0.194	-0.222	0.042	-0.051	0.256	0.186	**0.855**	0.423	0.449	0.034	**0.819**	0.047	1.000	
Zn	0.281	-0.262	0.102	-0.029	0.232	0.286	**0.723**	0.399	0.533	0.117	**0.777**	-0.002	**0.650**	1.000

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