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Monitoring of Finnish arable land: changes in soil quality between 1987 and 1998

Ritva Mäkelä-Kurtto and Jouko Sippola
MTT Agrifood Research Finland, Environmental Research, FIN-31600 Jokioinen, Finland,
e-mail: ritva.makela-kurtto@mtt.fi

This study is part of the long-term monitoring of Finnish arable land and it is based on soil analyses of 705 monitoring sites sampled in 1998. The same sites were sampled twice previously, in 1974 and 1987. We describe here the state of the Finnish cultivated soils in 1998 and changes in soil quality since 1987. The samples were analysed for organic C, volume weight, pH, P, K, Ca, S, Mg, Al, B, Cd, Co, Cr, Cu, Fe, Mn, Mo, Se and Zn. Macronutrients were extracted with 0.5 M ammonium acetate + 0.5 M acetic acid (pH 4.65) and most micronutrients, Al and heavy metals with the same solution + 0.02 M Na_2EDTA. Hot water was used to extract B and Se.

From 1987 to 1998, soil P, Ca, Mg, S, Cr, Cu, Zn, volume weight and electrical conductivity increased and soil K, B, pH and organic C decreased. There was no change in soil Al, Cd, Mn and Ni. Between 1987 and 1998, the use of P, K, B and Cu in mineral fertilisers declined whereas that of Ca in liming agents and Zn in mineral fertilisers increased. With the exception of P and Cu, these changes affected the concentrations of easily soluble macro- and micronutrients in the soil accordingly. The slight decrease in soil pH might be due to the increase in the use of fertliser N. The finding that soil Cd and Ni ceased to increase and that soil Cr increased only slightly was attributed to the dramatic reduction in national emissions and bulk depositions of heavy metals.

Key words: cultivated soil, heavy metals, macronutrients, trace elements, soil monitoring, soil testing

Introduction

The quality of cultivated soils is of a great agricultural, nutritional and environmental importance to society. Soil can be considered as the most valuable natural resource for our food supply, as 95% of protein and most of the calories needed by human population are obtained from traditional land-based agriculture (Botkin and Keller 1995). Fertile, uncontaminated soil can yield crops sufficient in quantity and high in quality. Soil quality is known to have marked effects on health (Oliver 1997). Furthermore, soil has impacts on the environment, particularly on the quality of surface waters and groundwaters.

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In Finland, the eutrophication of the surface waters is caused mainly by N and P leached from arable land. Agriculture and other human activities affect soil quality and soil physical, chemical and biological processes. Soil is susceptible to pollutant inputs from natural and anthropogenic sources, such as atmospheric depositions and agro-chemicals. One of the most harmful pollutant groups in the food chain is heavy metals.

The state of cultivated soils has been monitored to help us meet the targets of sustainable agriculture, to maintain high quality of the crops and to reduce nutrient load on waters. Monitoring is a way of following-up soil quality and changes in it with time. These changes are caused mainly by agricultural management practices such as fertilisation, liming, and the application of manure and organic soil improvers including sewage sludge. Atmospheric deposition is a significant source, at least locally, of some elements, e.g., polluting heavy metals.

This study was conducted as part of the long-term monitoring of Finnish cultivated soils. Soil quality was analysed by using methods applied in Finnish soil testing (Vuorinen and Mäkitie 1955, Lakanen and Erviö 1971). The fertiliser recommendations and restrictions set out in EU agri-environmental legislation and financial support received from the EU are based on soil testing, too. The same analytical methods were used in a global FAO soil testing project (Sillanpää 1982, 1990, Sillanpää and Jansson 1992, Jansson 1995).

Finland has two monitoring networks for cultivated soils, one comprising 705 sites, which has been operating at country level since 1974, and a smaller one with 122 sites, which was set up at experimental stations of MTT Agrifood Research Finland since 1992 (Starr et al. 2000). The monitoring of arable land at country level began in 1974 with the collection of soil samples from 2000 field plots throughout the cultivated area (Sippola and Tares 1978). In 1987, 1320 sites of the same fields were resampled in a project under the Finnish Acidification Programme (Erviö et al. 1990). In 1998, the same monitoring sites, covering a total of 705 fields, were sampled for a third time.

The main aims of this study were to present the state of Finnish cultivated soils in 1998, changes in soil quality since 1987 and to establish the most probable reasons for the changes. Excluding phosphorus, sulphur, copper and zinc, analytical results were not presented in this paper by cultivation zone, because the data for 1998 did not differ markedly from those for 1987, which were published earlier (Erviö et al. 1990). Also, the distributions of element concentrations of the soils in 1987 are available in the earlier publication.

Material and methods

This long-term soil monitoring study has been conducted by keeping the sampling sites, season and methods unaltered since the beginning. Thus, in 1998, soil samples were collected from the surface layer (0–20 cm) of arable land as four subsamples from each corner of a 10 × 10 m sampling area as they had been in 1974 (Sippola and Tares 1978) and in 1987 (Erviö et al. 1990). The sampling season was early summer, by which time timothy had formed a full spike. Note that all fields had most likely been fertilised 1–2 months before the time of sampling. The number of sampled sites totalled 705 (Fig. 1). The samples were air-dried and passed through a 2-mm sieve before analysis.

Soil analyses methods employed in 1998 were the same as those used in the previous monitoring studies (Erviö et al. 1990) and in the soil testing of cultivated soils in Finland (Agricultural Research Centre 1986, Viljavuuspalvelu 2000). Electrical conductivity (EC) and pH(H_2O) were measured from a soil-water suspension (1:2.5). Volume weight was determined by weighing 25 ml of air-dried and ground soil. Carbon (C) content was determined by an automated dry ashing method (LECO CR-12, St. Joseph, MI, USA.) assuming that the sample contained only organic C. For the air-dried soil samples, 0.5 M ammonium acetate + 0.5 M acetic acid (pH 4.65, AAAc) (1:10, 1 h) was used to extract the macroelements phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S) and 0.5 M ammonium acetate + 0.5 M acetic acid + 0.02 M Na_2EDTA (pH 4.65, AAAc-EDTA) (1:10, 1 h) was used to extract aluminium (Al), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). Boron (B) and selenium (Se) were extracted with boiling water (1:2, 5 min, 1:4, 30 min, respectively). All the reported results were based on 25-ml soil volumes taken for extraction. Concentrations of P were measured by spectrophotometry, K, Ca, Mg, S, Al, B, Cd, Co, Cr, Cu, Fe, Mn and Zn by inductively coupled plasma emission optic spectrometry (ICP-OES), Mo by graphite furnace atomic absorption spectrometry (GF-AAS) and Se by inductively coupled plasma mass spectrometry (ICP-MS). A main difference in the laboratory devices used for the measurements of soil characteristics between 1987 and 1998 was that the concentration of Cd in the soil extracts were measured by AAS using an air-acetylene flame in 1987 (Erviö et al. 1990).

Due to the non-normality of distributions, statistical evaluation of analytical results was carried out by the sign test of the UNIVARIATE procedure (SAS 1999). Test statistics were calculated from the difference in data from the same site between 1987 and 1998. Probabilities $P < 0.05$ of the sign test value for analysed soil properties were considered to indicate a significant change between 1987 and 1998.

Results and discussion

Soil types and general soil characteristics

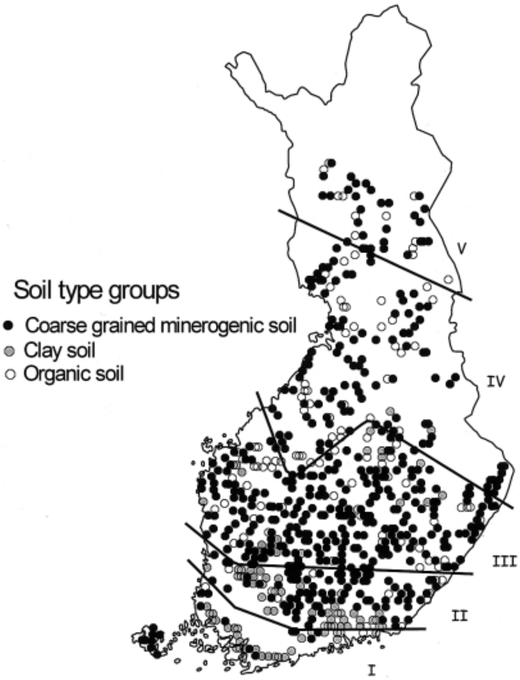

Fig. 1. Sampling sites (n = 705) in 1998 by the soil type groups and by the plant cultivation zones, I–V.

Soil types. In 1998, the 705 soil samples (Fig. 1) were classified into soil type groups as follows: coarse grained minerogenic soils (sands and silts) 69%; clay soils (clay content > 30%) 14%; and organic soils (humus content > 20%) 17%. The figures for 1987 were 67%, 14% and 19%, respectively, indicating that some soils classified as organic in 1987 had been converted due to organic matter decomposition into coarse grained minerogenic soils by 1998.

Organic carbon. The median organic C content of the soils in 1998 was down by 8% on 1987 whereas the median soil volume weight was up by 5% (Table 1). These small changes might be due to the decomposition of organic matter and to soil compaction. Soil volume weight is known to depend on the humus content (Erviö 1970). Moreover, current cropping systems favour decomposition of soil organic matter (Erviö 1995). Organic C content was higher, on average, in the north than in the south of the country due to the abundance of peat and other organic soils in northern Finland (Fig. 1).

Soil pH. Monitoring of Finnish arable land indicated that soil pH(H_2O) had a decreasing trend, because the median soil pH value in 1998 was 0.07 units lower than the respective value in 1987. The statistics of Viljavuuspalvelu (2002) also showed an increase in the acidity of Finnish cultivated soils during the study period.

In 1987–1998, the amount of liming agents applied annually to the cultivated area rose, annual sales increasing from 774 143 t (339 kg ha^{-1}) in 1974–1986 to 888 540 t (460 kg ha^{-1}) in 1987–1998 (Kemira Agro 1999). As to acidifying emissions into the air in Finland, annual sulphur dioxide (SO_2) emissions fell from over 300 kt to 90 kt in 1987–1998 but annual nitrous oxide (NO_x) emissions remained fairly constant, at 250–300 kt (Saarinen 2001). In cultivation zone I, bulk deposition of sulphate as sulphur (SO_4-S) was about 5–10 kg, of nitrate as nitrogen (NO_3-N) 2–4 kg and of ammonium as nitrogen (NH_4-N) 2–5 kg ha^{-1} in 1987–1998; in cultivation zone V, the figures were about 2 kg, 1 kg and under 1 kg, respectively (Leinonen 1999a, b). Depositions were higher in the south than in the north of Finland due to the long-range transport from other European countries including Russia.

Obviously, atmospheric deposition had a minor effect on the pH of cultivated soils in 1987–1998. The main causes of acidification of cultivated soils in Finland are the application of fertilisers to the soil and the uptake of nutrients by plants from the soil. In 1987–1998, the mean annual use of N fertilisers was 97 kg ha^{-1}. This figure was 14 kg higher than the respective figure in the previous monitoring period (Kemira Agro 1999) and may largely explain the decrease in soil pH despite the increased use of liming materials.

Electrical conductivity. There was a relatively large difference (25%) in EC between the data for 1987 and 1998. The discrepancy was most likely due to periodical fluctuations in values caused by variable weather conditions. The EC level was still very low, however, and no problems are foreseen.

Macronutrients

Phosphorus. In 1998, the median soil P value for all the fields studied was 8.5 mg l^{-1}, which was 17% higher than the respective value in 1987 (Table 1). In 1998, the number of fields with a low P value was conspicuously lower, but there were also more fields with a high P value than in 1987 (Fig. 2). There were not big differences in the P value between soil type groups, on average (Fig. 3). In 1998, regionally, the highest mean P value occurred in the southernmost Finland (Fig. 4). Other data (Viljavuuspalvelu 2002, Palva et al. 2001) also indicate an increasing trend in the soil P value.

During the monitoring period, the mean annual application rate of P in mineral fertilisers declined by two-thirds, from 31 kg in 1987 to 12 kg ha^{-1} in 1998. Implementation of the EU agroenvironmental programme in Finnish agriculture in the 1990s reduced the use of P in fertilisation. The average amount of P added as mineral fertilisers during the period was 22 kg ha^{-1} yr^{-1} (Kemira Agro 1999). The average application rate of P fertilisers was down by 7.5 kg ha^{-1} on the previous study period. The average amount of P from animal manure, if it is considered to be applied evenly to the whole cultivated area, remained the same, about 10 kg ha^{-1} yr^{-1} (Yli-Halla et al. 2001). Finnish data on P depositions were not available, but P inputs from the atmosphere in Continental Europe have varied between 0.05 and 1.1 kg ha^{-1} yr^{-1} (Gibson 1997). Uptake of P by the most common Finnish crops has long been about 10 kg ha^{-1} yr^{-1}. Losses of total P from agriculture to surface waters in Finland has varied between 0.6 and 1.8 kg ha^{-1} yr^{-1} (Rekolainen et al. 1997). The P balance in Finnish cultivated soils at country level was still positive, the P application rate being high at the beginning of the study period. Soil P storage increased substantially and this was not compensated by the lower application rates used later, which were still above the average P uptake of the crop. As a result, the total amount of P in the plough layer increased annually by about 10 kg ha^{-1} in 1987–1998. This clearly led to P test value.

Table 1. Medians and means ± standard deviation of chemical characteristics of soils (n = 705) in 1998 as well as their differences from 1987.

	Median 1998 (mg l^{-1})	Difference from 1987 (mg l^{-1})[1]	%	Mean ± SD 1998 (mg l^{-1})	Difference from 1987 (mg l^{-1})	%
pH(H_2O)	5.8	– 0.07***		5.8 ± 0.5	– 0.04	
Org. C, %	3.3	– 0.28***	– 8	8.3 ± 11.0	– 0.73	– 9
Volume weight	1.0	+ 0.05***	+ 5	1.0 ± 0.2	+ 0.04	+ 4
El. cond. 10^{-4}S cm^{-1}	0.9	+ 0.18***	+ 25	1.1 ± 0.7	+ 0.24	+ 28
Ca	1237	+ 46**	+ 4	1436 ± 917	+ 89	+ 7
K	91	– 4*	– 4	111 ± 79	– 3	– 2
Mg	161	+ 6*	+ 4	202 ± 164	+ 14	+ 7
P	8.5	+ 1.2***	+ 17	13.1 ± 15.1	+ 2.3	+ 22
S	18	+ 2.8***	+ 18	25 ± 33	+ 5.3	+ 28
Al	438	+ 5.1NS	+ 1	493 ± 276	– 4.8	– 1
B	0.52	– 0.01*	– 2	0.59 ± 0.30	– 0.03	– 5
Cd	0.073	+ 0.002NS	+ 2	0.080 ± 0.042	+ 0.003	+ 4
Co	0.52	– 0.02**	– 4	0.64 ± 0.50	– 0.02	– 4
Cr	0.28	+ 0.02***	+ 6	0.36 ± 0.29	+ 0.02	+ 7
Cu	3.6	+ 0.48***	+ 17	4.5 ± 3.7	+ 0.60	+ 15
Fe	519	+ 20**	+ 4	742 ± 685	+ 20	+ 3
Mn	43	– 0.3NS	– 1	58 ± 74	0	
Mo	0.039	– 0.002**	– 5	0.057 ± 0.070	– 0.008	– 12
Ni	0.61	+ 0.01NS	+ 2	0.98 ± 1.03	+ 0.01	+ 1
Se	0.009			0.010 ± 0.005		
Zn	3.0	+ 0.38***	+ 16	4.3 ± 4.1	+ 0.79	+ 22

[1] Statistical significance: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS not significant

Potassium. During the monitoring period, soil K decreased. Restrictions on the use of N and P in fertilisation also reduced the use of K in mineral fertilisers, from 57 kg ha^{-1} in 1987 to 33 kg ha^{-1} in 1998. In 1987–1998, the mean annual application rate of K was 44 kg ha^{-1}, which was 7 kg less than that in 1974–1987 (Kemira Agro 1999). Research results of Viljavuuspalvelu (2002) were consistent with the present findings. Potassium concentrations were highest in clay soils, the bulk of which are located in southern Finland (Fig. 1).

Calcium. Soil Ca increased by 4% in 1987–1998, in harmony with the increase in the use of liming agents during the same period. Likewise soils analysed by Viljavuuspalvelu (2002) showed that the Ca level in 1998 was the same as or slightly higher than in 1986–1990 and in 1991–1995. Coarse grained minerogenic soils had lower Ca values than either of the other soil type groups had. There was a decreasing trend in soil Ca towards the north, because coarse grained minerogenic soils were more abundent there than in the south (Fig. 1).

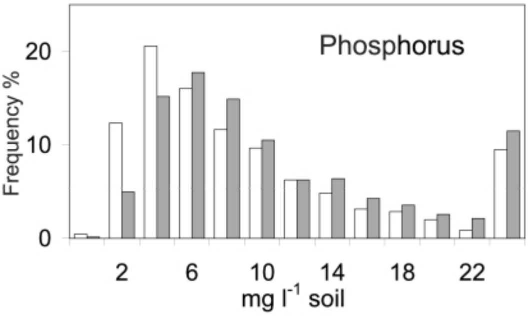

Fig. 2. Distribution of soil extractable phosphorus in 1987 (☐) and in 1998 (▨).

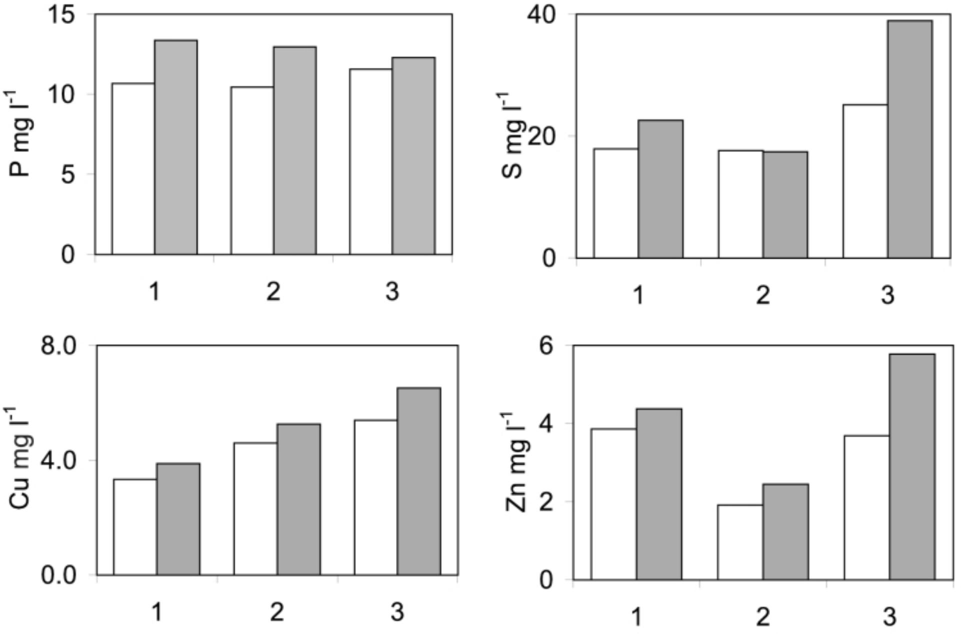

Fig. 3. Means of extractable phosphorus (P), sulphur (S), copper (Cu) and zinc (Zn) by the soil type groups, 1 = coarse grained minerogenic soils, 2 = clay soils, 3 = organic soils, in 1987 (□) and in 1998 (▨).

Magnesium. Soil Mg was 4% higher in 1998 than in 1987 owing to the higher amounts of Mg added to the soil with mineral fertilisers. During the previous monitoring period, the mean annual Mg input from fertilisers was 3.7 kg ha^{-1} and during the present period 4.7 kg ha^{-1}. However, at the closing years of the 1990s, annual Mg inputs from fertilisers were less than 3 kg ha^{-1}. Another source of Mg was liming agents, mean annual sales of which increased after 1987; statistics on the input rates were not, however, available. Magnesium concentrations were lowest in coarse grained minerogenic soils. According to the analytical data of Viljavuuspalvelu (2002) soil Mg in the Finnish fields increased from 1986–90 to 1996, but decreased thereafter.

Sulphur. In 1998, soil S was 18% higher than in 1987. According to another monitoring study of Finnish cultivated soils, the S value rose by 15% in 1992–1997 (Sippola et al. 2001). Both emissions and bulk depositions of S decreased markedly during this monitoring period. Other potential sources of S in the soil are fertilisers and animal manure. Mineral fertilisers sold by Kemira Agro (2002) for cereals, grass, beets and potatoes in Finland contain 2–3%, 2–3%, 8% and 10–17% S, respectively. At the end of 1980s, the contents were lower (Hero 2001, personal communication). There were no analytical data on the S content of animal manure in Finland. In Sweden, cattle and swine solid manure contained about 0.5% S in dry matter (Steineck et al. 1999, Eriksson 2001). The introduction of new feeding regimes and animal handling systems has caused major changes to the contents of some nutrients in animal manure since 1950s. In Denmark, the mean S input from animal manure into the cultivated soils at country level was estimated to be 8 kg in 1994 (Eriksen 1997). In 1998, organic soils contained more S than did the other soil type groups (Fig. 3), which explains the higher S concentrations in the soils of northern Finland (Fig. 4).

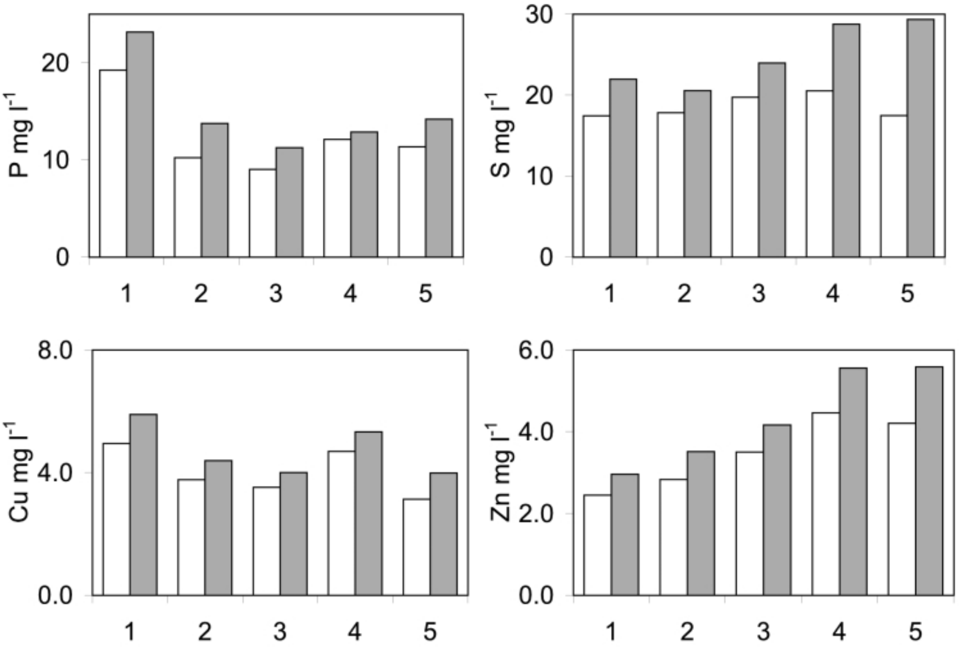

Fig. 4. Means of extractable phosphorus (P), sulphur (S), copper (Cu) and zinc (Zn) by the plant cultivation zones, 1–5, in 1987 (□) and in 1998 (■).

Microelements and Al

Aluminium. Extractable Al was unchanged in 1998 (Table 1), being at the same level as in 1987 (Erviö et al. 1990). Concentrations of soluble forms of Al are known to depend on the pH level of the soils, and hence the Al values were higher in organic soils than in the other soil type groups, on average.

Boron. From 1987 to 1998, soil B decreased. The change was due to the marked reduction in B fertilisation, the amount of B applied to the soil in mineral fertilisers being 242 g ha^{-1} in 1987 and 95 g ha^{-1} in 1998. The B values were highest in the southernmost Finland.

Cadmium. In 1998, soil Cd was at the same level as it had been in 1987 (Table 1). P fertilisers are usually the main source of Cd in the cultivated soil. The Cd concentration of P fertilisers depends on the Cd content of the phosphate used as raw material. In the early 1980s, a phosphate mine was opened at Siilinjärvi, and since then Cd inputs from fertilisers have decreased gradually. Since 1986, only 30–100 mg Cd has been allowed in each kg of fertiliser P. In 1999, a mean annual Cd input from the mineral fertilisers was 0.025 g ha^{-1} (Mäkelä-Kurtto and Sippola 2001). Surveys of atmospheric heavy metal deposition monitored by moss analyses in the Nordic countries since 1969 and later in other European countries, too, indicate a steady decline in depositions of most heavy metals (Rühling and Steinnes 1998, Finnish Forest Research Institute 2001). In Finland, total annual emissions of Cd into the air from various sources fell by 80% from 6.3 t in 1990 to 1.1 t in 1997 (Melanen et al. 1999). In 1996, domestic sources contributed 33%, natural and global sources 17% and emissions from Russia, Poland and the United Kingdom combined 28% of total Cd depositions in Finland (Ryaboshapko et al. 1999). In 1997–1999, the mean Cd deposition was 0.19 g ha^{-1} yr^{-1} with a range of 0.04 to 0.41 g ha^{-1} yr^{-1} (Leinonen 1999a, b, Waldén et al. 1999, Leinonen 2000). Cadmium depositions, like soil Cd, decreased northwards. In the mid-1990s, average total Cd input to cultivated soil was lower in Finland than in any other OECD countries (Folke and Landner 1996). The results of static and dynamic mass balance estimates (Ministry of Agriculture and Forestry 1997, Louekari et al. 2000, Mäkelä-Kurtto and Sippola 2001) show that Cd inputs to the soil from various sources and Cd outputs from the soil to crops and waters are in balance. Hence, no significant change in soil Cd could be observed in the present study.

Cobalt. A slight decrease in soil Co was obvious in 1987–1998. No data on the Co inputs into cultivated soils or on the changes in them with time were available in Finland.

Chromium. Soil Cr level rose by 6% in 1987–1998, which was less than in the previous monitoring period (Erviö et al. 1990). This is most probably a consequence of the reduction in Cr emissions into the air, from 32 t in 1990 to 21 t in 1997 (Melanen et al. 1999). In 1997–1999, an estimated average Cr input via atmospheric deposition was 0.52 g ha^{-1} yr^{-1}, ranging from 0.13 g ha^{-1} yr^{-1} in northern Finland to 1.32 g ha^{-1} yr^{-1} in the south of the country (Leinonen 1999a, b, Waldén et al. 1999, Leinonen 2000). In Sweden, the Cr contents of animal manure were about 10 mg kg^{-1} dry matter (Eriksson 2001) and have declined since the 1970s (Steineck et al. 1999). In Finland, no analytical results were available on the Cr contents of animal manure. According to the estimates of Mäkelä-Kurtto and Sippola (2001), the average annual Cr input from mineral fertilisers in Finland was typically 2.8 g ha^{-1} and from liming agents 7.7 g ha^{-1} in 1999. The highest median Cr content in 1998 was recorded in soils in northern Finland.

Copper. The median value of soil Cu in 1998 was 17% higher than that in 1987 (Table 1). The rate of increase was, however, slower than it had been in 1974–1987 (Erviö et al. 1990). The difference between the two monitoring periods was mainly due to the reduction in Cu inputs from mineral fertilisers by nearly 90%, from 275 g ha^{-1} in 1987 to 33 g ha^{-1} in 1998. Moreover, annual Cu emissions from domestic sources decreased by 23% from 94 to 72 t, in the 1990s (Melanen et al. 1999). In 1997–1999, the mean bulk deposition of Cu was 5.1 g ha^{-1} yr^{-1}, ranging from 3.0 to 9.4 g ha^{-1} yr^{-1} and being highest in the south of the country (Leinonen 1999a, b, Waldén et al. 1999, Leinonen 2000). In 1997, an average Cu input from the total amount of animal manure generated was estimated to be 105 g ha^{-1}, if the manure is considered to be applied evenly to the whole cultivated area (Mäkelä-Kurtto and Sippola 2001). According to Mäkelä-Kurtto and Sippola (2001) the soil Cu balance was clearly positive at the end of 1990s, which was a reason for the increase in soil Cu value observed here. The highest Cu value was in organic soils and the lowest one in coarse grained minerogenic soils, on average (Fig. 3), but differences were small. There was not a clear geographical trend in the Cu values (Fig. 4).

Iron. After 1987, soil extractable Fe increased by 4%. Organic soils had higher concentrations of Fe than did the other soil type groups. In 1997–1999, approximately 10 times as much Fe was deposited annually in the southern Finland, 200–300 g ha^{-1}, as in the north, 25–40 g ha^{-1} (Leinonen 1999a, b, 2000). The highest median of soil Fe was in cultivation zone IV.

Manganese. Soil Mn remained unchanged in 1987–1998, there being no major changes in average annual Mn inputs from mineral fertilisers between the monitoring periods: 199 g ha^{-1} in 1974–1986 and 216 g ha^{-1} in 1987–1998, on average (Kemira Agro 1999). The highest Mn values were recorded in organic soils and in the northernmost cultivation zone.

Molybdenum. In 1987–1998, soil Mo started to decline, particularly in organic soils. The lowest median of soil Mo was in the cultivation zone IV.

Nickel. No change in soil Ni occurred in the period 1987–1998, although national Ni emissions into the air fell by 60%, from 67 t in 1990 to 28 t in 1997 (Melanen et al. 1999). The average Ni input via atmospheric deposition in 1997–

1999 was 1.5 g ha^{-1} yr^{-1}, ranging from 0.8 g ha^{-1} yr^{-1} in the north to 2.5 g ha^{-1} yr^{-1} in the south of Finland (Leinonen 1999a, b, 2000). According to Swedish studies (Eriksson 2001) Ni contents in animal manure were about 5 mg kg^{1} dry matter and have decreased slightly since the 1970s (Steineck et al. 1999). Even though we lack evidence as yet, Ni inputs from manure to cultivated soils may be of importance in Finland, too. In 1999, the average amount of Ni added via mineral fertilisers was 1.5 g ha^{-1} and via liming agents 6.1 g ha^{-1} (Mäkelä-Kurtto and Sippola 2001). In 1998, Ni concentrations in soils were higher in the south than in the north of Finland and higher in the clay soils than in the other soil type groups.

Selenium. Selenium was included in the monitoring program for the first time. Concentrations of Se decreased northwards. In 1984, it became legal to add Se to all mineral fertilisers sold in Finland owing to the low soil Se content and insufficient Se concentrations in food, cereals in particular, and in feedstuffs. Fertilisers have contained 6–16 mg kg^{-1} Se.

Zinc. In 1987, many of Finland´s fields were low in Zn. The need to raise the Zn concentration in feedstuffs led to an increase in Zn fertilisation. In 1987–1998, the median of soil Zn increased by 16% (Table 1), largely due to the increase in annual Zn inputs from mineral fertilisers, from 60 g ha^{-1} in 1974–1986 to 136 g ha^{-1} in 1987–1998. Thus, Zn additions from fertilisers more than doubled during this monitoring period. However, Zn emissions into the atmosphere fell by 85% from, 571 t to 70 t per year, in the 1990s (Melanen et al. 1999). In 1997–1999, the mean Zn input from the atmosphere was 20.2 g ha^{-1} yr^{-1} and the range from 4.0 to 52.7 g ha^{-1} yr^{-1} (Leinonen 1999a, b, 2000). Average Zn deposition was about three times as high in southernmost as in northernmost Finland. The lowest mean Zn value was in clay soils (Fig. 3). Soil Zn increased northwards (Fig. 4), as organic soils and grasslands, which needs Zn-rich fertilisation, are located mainly in the north of country. The positive mass balance of soil Zn recorded by Mäkelä-Kurtto and Sippola (2001) in the late 1990s is consistent with the increase in soil Zn found here.

Conclusions

Between 1987 and 1998, the most significant changes in the soil nutrient concentrations seemed to occur in those of P, S, Cu and Zn, which rose by nearly 20%. Small increases occurred in soil Ca, Mg and Fe. The decreases found in soil K, B, Co and Mo values were minor. Most of the changes in the soil nutrients could be attributed to changes in the use of nutrients in mineral fertilisers. The exceptions were the soil P and Cu, which increased even though use of these nutrients declined markedly during the study period. However, total inputs of P and Cu into the soil were still so high that the mass balances continued to be strongly positive, leading to the nutrient increases documented here. The major increase in soil Zn was mainly due to the heavy increase in fertiliser Zn, a finding that was also supported by the positive mass balance in soils. The trend in soil P observed here may aggravate the risk of eutrophication, whereas trends in soil Ca, Mg, Cu and Zn may lead to improvements in the quality of crops.

As to harmful heavy metals, soil Cd and Ni concentrations did not change, but that of Cr increased slightly. Clear reductions in the Cd inputs from fertilisers and the atmosphere compared with the previous monitoring period brought soil Cd inputs and outputs into balance. This levelling-off of concentrations of Cd and Ni in the soil is a positive sign for the agro-ecosystem and agricultural products, too.

The level of soil acidity rose, even though use of liming agents increased and acidifying depositions declined noticeably. The main reason would seem to be the increase in the use of fertiliser N. Acidification of the cultivated soils is undesirable because it may reduce the availability of nutrients and increase the availability of heavy metals to plants and also accelerate leaching of the metals to waters.

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SELOSTUS

Suomalaisten viljelymaiden tilan seuranta: muutoksia peltojen ominaisuuksissa aikavälillä 1987–1998

Ritva Mäkelä-Kurtto ja Jouko Sippola
MTT (Maa- ja elintarviketalouden tutkimuskeskus)

Tutkimus oli osa viljelymaiden pitkäaikaista seurantaa, joka on alkanut vuonna 1974 ja jonka tavoitteena on ollut tuottaa aikaan ja paikkaan sidottua tietoa peltojen kemiallisista ominaisuuksista ja niissä tapahtuneista muutoksista. Tämän tutkimusosuuden tarkoituksena oli seurata maan ominaisuuksien kehittymistä aikavälillä 1987–1998. Tavoitteena oli saada kattava kuva peltomaiden tilasta vuonna 1998 sekä peltomaissa tapahtuneista muutoksista vuodesta 1987 ja muutosten aiheuttajista. Maanäytteet kerättiin vuonna 1998 samoilta 705 peltolohkolta, jotka sijoittuivat tasaisesti koko viljellylle alueelle, ja analyysituloksia verrattiin vuoden 1987 vastaaviin tuloksiin. Näytteistä määritettiin maalaji, pH, orgaaninen hiili (C), johtoluku, tilavuuspaino, helppoliukoiset pää- ja hivenravinteet sekä helppoliukoiset raskasmetallit. Analyysimenetelmät olivat samat kuin tavanomaisessa viljavuustutkimuksessa. Fosfori, kalium, kalsium, rikki ja magnesium uutettiin maanäytteistä liuokseen (AAAc, pH 4,65), joka oli 0,5 M ammoniumasetaatin ja 0,5 M etikkahapon suhteen, ja alumiini, kadmium, koboltti, kromi, kupari, rauta, mangaani, molybdeeni ja sinkki muuten edellisen kaltaiseen liuokseen (AAAc-EDTA, pH 4,65) paitsi, että liuos oli myös 0,02 M natriumetyleenidiamiinitetraetikkahapon (Na_2EDTA) suhteen. Boorin ja seleenin määrittämiseksi maanäytteet uutettiin kuumaan veteen. Johtoluku ja pH mitattiin vesiuutteesta.

Merkittävimpiä ravinnemuutoksia vuodesta 1987 vuoteen 1998 olivat helppoliukoisen fosforin, rikin, kuparin ja sinkin lisääntyminen lähes 20 prosentilla. Kalsiumin, magnesiumin ja raudan pitoisuudet lisääntyivät hiukan, ja kaliumin, boorin, koboltin ja molybdeenin pitoisuudet vähenivät lievästi. Muutokset peltojen ravinnepitoisuuksissa olivat yleensä seurausta lannoitteiden käyttömäärissä tapahtuneista vastaavista muutoksista. Sen sijaan fosfori- ja kuparipitoisuudet nousivat, vaikka vastaavat ravinnelisäykset lannoitteissa huomattavasti vähenivät tutkimusjakson aikana. Fosfori- ja kuparipitoisuuksien nousun maassa selitti se, että näiden aineiden lisäykset maahan olivat kuitenkin vielä selvästi suuremmat kuin näiden aineiden poistumat maasta.

Viljelymaiden todettiin lievästi happamoituneen, vaikka kalkitusaineiden käyttö lisääntyi. Lasku pH-luvussa johtui ilmeisesti siitä, että lannoitetyppeä käytettiin aikavälillä 1987–1998 keskimäärin jonkin verran runsaammin kuin edellisellä tutkimusjaksolla 1974–1987.

Haitallisten raskasmetallien pitoisuudet kehittyivät suotuisasti, sillä helppoliukoisen kadmiumin ja nikkelin pitoisuudet maassa pysyivät ennallaan ja kromin pitoisuus kasvoi vain vähän. Syy myönteiseen kehitykseen oli raskasmetallipäästöjen ja -laskeumien oleellinen pieneneminen.