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35-year trends of acidity and soluble nutrients in cultivated soils of Finland

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ABSTRACT

Nutrient status of arable soils is linked to food production potential and environmental risks. The use of nutrients is affected by policy measures, which formulation calls for data on the long-term development of soil fertility. In Finland, the chemical status (pH 4.65 ammonium acetate-extractable nutrients and pH_w) of cultivated topsoils has been surveyed at the same sites in 1974 ($n = 1835$), 1987, 1998 and 2009 ($n = 524$). The aims of this study were to determine the temporal trends in P, S, macro nutrient cations and pH utilizing the monitoring data, to find explanations for the trends, and to assess the current status of fertility in the Finnish cultivated soils. The mean soil P concentrations continuously increased with time in clay, fine-textured and mull soils, or first increased but later turned to a decrease in coarse mineral soils, and exhibited no trend in peat soils. Between 1998 and 2009, high P concentrations tended to decrease whereas low P increased, the magnitude of the change being dependent on cropping system (if >80% of the time planted with annual crops, perennial crops, or under rotation of the two). The trends of the other nutrients mostly reflected the balances of the elements in agricultural soils. The trend for S was generally increasing between 1987 and 1998, but turned to a decline after 1998. The general trends in the mean Ca, Mg and pH were increasing, whereas the initial upward trend for K leveled off after 1987. Based on the 2009 sampling, the current soil fertility is sufficient, but attention is to be paid on S and K status, and the overall fertility of coarse mineral soils.

1. Introduction

Studies on the nutrient status of soils are driven by three fundamental challenges, (1) understanding the processes involved in the cycling of elements in terrestrial systems, (2) improving guidance to farmers on efficient use of nutrients in order to maximize plant production or its profitability, or both, and (3) identifying practices that pose a risk for nutrient loading to waterways (Hedley, 2008). A lack in the availability of any essential element, or nutrient imbalances in soil, may markedly decrease the quantity and quality of crop yields, thus potentially compromising food security. A build-up of nutrient reserves in soils by over-fertilization, on the other hand, leads to economic inefficiency and negative environmental impacts, for example eutrophication of waterways due to agricultural P loading (e.g., Granlund et al., 2005, Ulén et al., 2007). Obviously, a balance between inadequacy and excessiveness in the nutrient content of cultivated soils is imperative for sustainable crop production (Matson et al., 1997, Tilman et al., 2002).

The importance of maintaining or enhancing the quality of soils is widely acknowledged (Blum, 2005, EC, 2006, Karlen et al., 2001) and soil protection policies like the Environmental Impact Assessment (Jay et al., 2007), the Agri-Environmental Measures (EC, 2005) and the Nitrates Directive (EEC, 1991) have been launched. To assess the effectiveness of soil protection measures and to correct them, monitoring of soils is essential. In most European countries, national soil monitoring programs exist, although sampling and testing protocols, spatial density of sampling, and frequency of re-sampling vary greatly between and even within countries (Arrouays et al., 2008a). Majority of the European soil monitoring networks have been established in the 1990s or later and have been sampled only 1 or 2 times (Arrouays et al., 2008b). In Finland, the national survey of cultivated soils dates back to 1974, and entails four sampling campaigns conducted at intervals of 11 to 13 years. Hence, the Finnish soil monitoring data offers an opportunity to explore the chemical status of cultivated soils over a period of almost four decades during which significant changes in the agricultural practices and policies have occurred.

A major underlying trend in the Finnish agriculture, starting already in the 1970s, has been the regional specialization to animal production and crop production in different areas (Hietala-Koivu, 2002, Voutilainen et al., 2012). This development was further accelerated after Finland joined the European Union and, in account of subsidy policies, milk production largely disappeared from the southern parts of the country. Changes in environmental policies, in turn, have affected P fertilization since findings on the deteriorating effects of agricultural nutrient flows on surface waters (Kauppi, 1984). Recently long-term soil monitoring data has shown a continuous decline in soil carbon, which calls

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for policy measures for preserving soil organic matter (Aakkula and Leppänen, 2014, Heikkinen et al., 2013).

The aims of this study were (1) to determine the mean temporal trends between 1974 and 2009 in the concentrations of macronutrients P, S, K, Ca, Mg, and of pH of the plough layer (typically about 20 cm deep) of cultivated soils, (2) to find explanations for the observed trends, and (3) to assess the current status of soil nutrient concentrations and pH. The results provide valuable information on the fertility of soils, e.g., for use as decision support for future updates of fertilizer recommendations and environmental protection policies.

2. Material and methods

2.1. Soil sampling

The Finnish national soil monitoring was launched in 1974 as a general inventory of the nutrient status of agricultural soils (Sillanpää, 1978). The sampling grid, which consisted of 2042 sites, was pre-designed on maps with a 1:2 000,000 scale to cover the whole agricultural area of the country (Sippola and Tares, 1978). The exact sampling locations were decided in the field by the sampling crews. From a given area, fields on which a common crop of that time, timothy (*Phleum pratense*), was grown were sought for sampling. Additional requirement was that the fields sampled were situated further than 400 m from a railroad or a highway, 100 m from a country road, 20 m from a farm lane and 50 m from an electric power line. The sampling site characteristics were documented by making a written description and marked on maps of scale 1:200,000.

The next re-sampling was done in 1987, but only 1362 sites were revisited (Erviö et al., 1990). The most remote parcels and those which were no longer under cultivation, or were difficult to locate reliably, were discarded. During the second sampling campaign, more detailed maps were drawn over the sites to ease their location in the future. During the third sampling campaign, conducted in 1998, samples collected decreased to 720 sites (Mäkelä-Kurtto and Sippola, 2002) and in 2009 the network was further reduced to 611 sites. The substantial reductions in the number of sites visited were mostly due to diminished resources, while elimination of the fields that were no longer under cultivation and of the sites where any ambiguity of correct location could arise contributed to the decrease. During the fourth sampling in 2009, the map coordinates of the sampling sites were determined with GPS. Spatial coverage of the whole country was ensured throughout the years (Fig. 1), despite of the continuation of decrease in the number of sampling sites. The current soil monitoring network represents fairly closely the typical arable land in Finland in respect of soil type and cultivated crop plants (Heikkinen et al., 2013).

While compiling the final data, the notes of the sampling crews were screened for unusual conditions, e.g. flooding or obvious disturbances such as removal of stones that could cause mixing of subsoil to the sampled soil layer, and data linked to such observations were omitted (see Heikkinen et al., 2013). Furthermore, in the statistical analyses of the data, 3 sites from the region east and 3 sites from the region north in 1974 were discarded due to missing soil type information. In the north region, all clay (3 sites in 1974) and mull soils (21 sites in 1974, 3 in 1987, 3 in 1998 and 2 in 2009) were omitted from the statistical analyses on the grounds of inadequate number of observations. The final number of sites included in the present study was 1835 in 1974, 1312 in 1987, 638 in 1998 and 524 in 2009.

At each sampling site, a composite soil sample was taken during early summer from the 0–15 cm surface layer of a 10 × 10 m sampling area. In 1974 and 1987, the samples were bulked from four subsamples taken from each corner of the sampling area with a spade. In 1998 and 2009, the composite samples consisted of about 10 subsamples taken with a soil auger (Ø 2 cm). Fresh plant material and larger roots were removed from each soil core together with the topmost part of soil rich in litter and root biomass. The samples were air dried, and ground to pass through a 2-mm sieve prior to laboratory analyses.

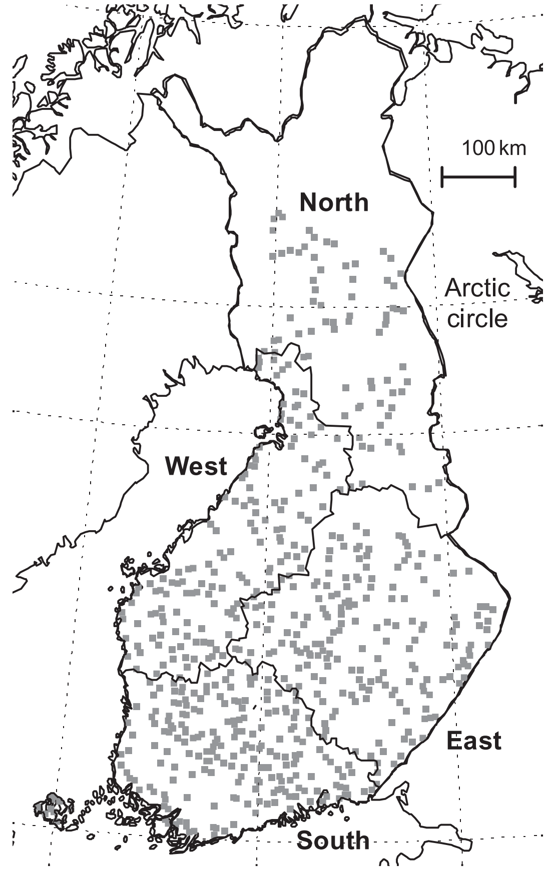

Fig. 1. The sampling sites of the monitoring network of cultivated soils in Finland in 2009. The regional division used in this study (south, east, west and north) is shown with solid lines.

2.2. Laboratory analyses

Macronutrients were extracted in a soil:solution ratio of 1:10 with a 0.5 M ammonium acetate-acetic acid solution, pH of which is adjusted to 4.65 (AAAc, Vuorinen and Mäkitie, 1955). The extraction was introduced to widespread use in Finland in the late 1940s after thorough method comparison studies, and subsequently it has been used in all laboratories undertaking soil testing in Finland. AAAc-extraction is based on displacement of surface-associated nutrient cations by NH_4^+ and H^+, but the extractant only solubilizes the most readily soluble fraction of soil P (Mäkitie, 1956). When compared to other, more widely known soil test methods, AAAc and Mehlich3 extraction (Mehlich, 1984) give equal results of extractable cations (Uusitalo et al., 2007), whereas for extracted P, AAAc gives very similar concentrations as extraction with deionized water at 1:60 soil:water ratio (see, e.g., Saarela et al., 2004).

The laboratory procedure involved shaking of 25 mL of soil in 250 mL of AAAc solution for 1 h in an end-over-end shaker at 27 rpm speed. Thereafter, the suspension was passed through a paper filter (Tervakoski, nominal pore size 8–10 μm). For quality control, every tenth sample was extracted in duplicate and in every extraction rack of ten bottles, one blank sample was included. One in-house reference sample was introduced per 200 samples.

The Ca and K concentrations of the soil samples collected in 1974 were determined from the extracts by a flame photometer, and the concentrations of Mg using atomic absorption spectrophotometer (AAS)