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Finnish trends in phosphorus balances and soil test phosphorus

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Soil test phosphorus (P) concentration has a major influence on the dissolved P concentration in runoff from agricultural soils. Thus, trends in soil test P partly determine the development of pollution potential of agricultural activities. We reviewed the changes of soil test P and P balances in Finnish agriculture, and assessed the current setting of P loss potential after two Agri-Environmental Programs. Phosphorus balance of the Finnish agriculture has decreased from +35 kg ha^{-1} of the 1980's to about +8 kg P ha^{-1} today. As a consequence, the 50-yr upward trend in soil test P concentrations has probably levelled out in the late 1990's, as suggested by sampling of about 1600 fields and by a modelling exercise. For the majority of our agricultural soils, soil test P concentrations are currently at a level at which annual P fertilization is unlikely to give measurable yield responses. Soils that benefit from annual P applications are more often found in farms specialized in cereal production, whereas farms specialized in non-cereal plant production and animal production have higher soil test P concentrations. An imbalance in P cycling between plant (feed) and animal production is obvious, and regional imbalances are a result of concentration of animal farms in some parts of the country. A major concern in future will be the fate of manure P in those regions where animal production intensity is further increasing.

Key-words: phosphorus, P balance, soil test P, farm type, P fertilization, Agri-Environmental Programs

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Introduction

Transport of P by runoff from agricultural land is one of the factors that is linked to eutrophication of surface waters. In Finnish environmental discussions, P is considered as a key driver of degradation of water quality of inland lakes and rivers, whereas either P or N may limit the growth of algae in marine environments (Kauppi 1984, Kirkkala et al. 1998). Agricultural land is a major source of P entering the surface waters (Rekolainen 1989, Valpasvuo-Jaatinen et al. 1997, Mitikka and Ekholm 2003).

There are a number of factors, such as topography, soil types, crops and tillage methods, that affect the magnitude of P losses from agricultural fields, and the effect of modifying one factor may strongly depend on the other settings. Reducing tillage intensity, as an example, may markedly decrease total P losses from steeply sloping fine-textured soils, but on other fields where erosion is smaller, reduced tillage may, in contrast, increase the off-site P transport (cf. Puustinen et al. 2005 and Uusitalo et al. 2007a). However, some factors operate in the same direction in all situations, and a well established example of that kind is soil P status: an increase in soil test P concentration inevitably increases P concentration of water draining from a given field (see e.g. Sharpley et al. 1978, Heckrath et al. 1995, Yli-Halla et al. 1995).

The objective of this work was to assess how two important factors affecting P loss potential from the Finnish agricultural soils – P balances and easily soluble soil P – have developed before and after the implementation of Agri-Environmental Programs since 1995. To do this, we reviewed national reports and journal articles concerning P use in Finland, and analyzed unpublished data that relate to P balances and soil P. In addition to making a nation-scale assessment on the development of soil P status so far, we also discuss current regional development in three areas with different types of agricultural production, and report typical soil test P concentrations at different types of farms.

Material and methods

Data sets

To analyze P balances and the development of soil test P concentrations in a national scale before and during the Agri-Environmental Programs, the following data sets were used:

(1) Balance sheet calculations collected for the OECD statistics (a national-scale calculation of P inputs and outputs according to the OECD guidelines)

(2) National-scale soil test P concentrations, consisting of (i) summaries of voluntary agronomic soil testing (data retrieved from soil testing laboratories), and (ii) a follow-up of the chemical status of agricultural soils in Finland done by MTT Agrifood Research Finland

(3) Soil test P concentration in a sample of 1600 agricultural fields in 1997 and 2002 (retrieved from the database of Viljavuuspalvelu Oy/Soil Analysis Service Ltd)

(4) In addition to the data described above, a model calculation of the national-scale development of soil test P concentrations was made using an equation, which was developed from Finnish long-term P fertilization trials.

Additional discussion on the probable developments in different regions is based on the following data sets:

(5) Agricultural Census of year 2004

(6) Personal communications with the regional authorities responsible for payments of farm subsidies

(7) Regional summaries of soil test P concentrations of voluntary agronomic soil testing retrieved from laboratories analysing soil samples

(8) Finally, data from the farmer interviews, which were part of the follow-up of the second Agri-Environmental Program (Mattila et al. 2007), were also included here to look for possible differences in soil test P concentrations in a farm-scale as related to the production line of the farms.

National-scale P balances

The data on P intputs and outputs were collected from national nutrient balance sheet calculations done at MTT Agrifood Reseach Finland. The balance calculation followed the OECD protocol (OECD 2001) modified for P balance calculation. The main elements taken into account as P inputs were mineral fertilizers, manures, organic fertilizers (sewage sludge), deposition, and P inputs with seeds and planting material. Outputs in this calculation included harvested food and industrial crops, and forage, with estimated pasture utilization.

National-scale soil test P concentrations

Data on soil test P [P_{Ac}, acid (pH 4.65) ammonium acetate-extractable soil P] concentrations were recently collected from commercial soil test laboratories, and published in Finnish as a part of the mid-term evaluation of the "Horizontal Rural Development Programme" (Ministry of Agriculture and Forestry, MMM 2004). The data consists of the results of agronomic soil analyses performed during 1997–2002 by the three largest soil laboratories in Finland (Viljavuuspalvelu Oy/Soil Analyses Services, Ympäristöpalvelu Oy/Environmental Services, and Sokerijuurikkaan tutkimuskeskus/Sugarbeet Research Institute). These laboratories are not the only ones making commercial soil tests, but they carried out the most part of the agronomic soil tests during the given period, and these data give a good idea of the population mean and distribution. More than 90% of the Finnish farms have participated in the Agri-Environmental Programs that oblige farms to test the fields for soil P in every five years. For agronomic soil testing, the recommended density of sampling is one sample per 1–3 hectares. Assuming that sampling density would be one sample per hectare, the part of our data that was associated with samples taken from three major agricultural regions in Finland (Uusimaa, Southwest Finland, and Ostrobothnia, Fig. 1) would cover 39–56% of the total field area. If each sample would represent 2 ha of field, at least 80% of the agricultural land in these three regions would be covered.

General summaries on soil test P concentrations, based on the analyses done at Viljavuuspalvelu Oy/Soil Analysis Service, are also referred to. These data are annually updated, and the most recent summaries can be found at their web sites www.tuloslaari.fi and www.viljavuuspalvelu.fi (click the tab labeled "Tilastotiedot"). Also these data alone have a fairly wide coverage, e.g. during 2001–2005, about 583 000 samples were analysed for soil test P in Viljavuuspalvelu Oy/Soil Analysis Service; even with 1-ha sampling density this is a good sample out of the total agricultural area of about 2.3 million hectares.

Soil test P of 1600 fields in 1997 vs. 2002

To make pairwise comparisons of P_{Ac} concentrations of the same fields between different dates, a separate dataset was retrieved from the archives of Viljavuuspalvelu Oy/Soil Analysis Service. Because soil test results can be ordered as posted

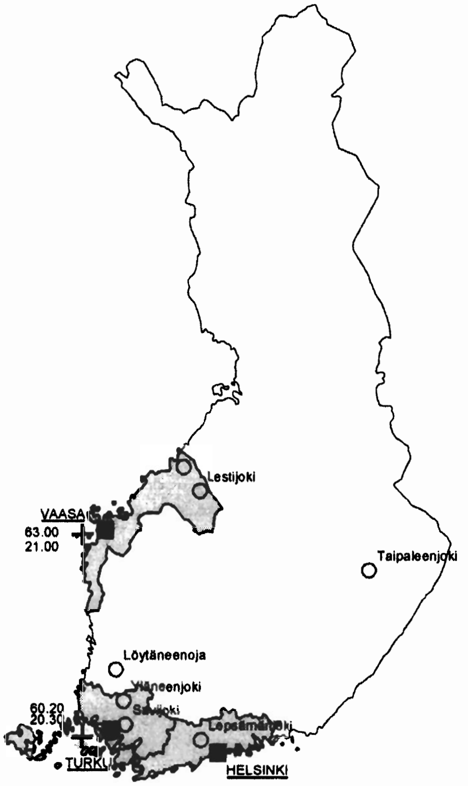

Fig. 1. Location of the three regions (Uusimaa, Southwest Finland and Ostrobothnia, all marked as grey) utilized as example areas of different regional development of agricultural production, and location of the MYTVAS-catchments.

to field maps, it is possible to identify results that represent the same field area in different samplings. For this study, the 2002 database of Viljavuuspalvelu Oy/Soil Analysis Service was searched for results that were ordered as posted to farm maps, followed by a search for the maps of the same fields from the older databases. About 1700 matches were found, and because the regular sampling interval is 5 years, the change in soil test P in this sample represents the change that has taken place between 1997 and 2002. For the analysis presented here, the data obtained was cleaned by filtering off suspiciously big changes. If the difference in soil test P concentrations during 5 years was larger than 90-%, these results were excluded due to probable errors in coding, sampling depths or sampling areas, etc. Finally, 1600 cases were left for the comparison.

Model calculations

Also model calculations can provide indications on the change in soil test P. In our modelling exercise, the equation generated by Ekholm et al. (2005), based on the results of the long-term field experiments of Saarela et al. (2006a, b), was utilized. The empirical equation estimates final soil test P (i.e. acid ammonium acetate-extractable P, P_{Ac}) concentration from an initial value (P_{Ac0}) after t years of cropping with a given P balance (P_{bal}). The equation has two parts, the first estimating the average change in soil test P at a given P balance, and the latter part conversing P to a less plant-available form with time (i.e., "aging" of P):

$$P_{Ac} = P_{Ac0} + (0.00084 \times P_{Ac0} + 0.0032) \times P_{bal} \times t - (0.0184 \times P_{Ac0} \times t).$$

For the model, the OECD nutrient balance calculations provided us with P_{bal}, whereas the initial level of P_{Ac} concentration ($P_{Ac0} = 11.8$ mg P_{Ac} l^{-1}; the average value for 1981–1985) was adopted from the data of Kähäri et al. (1987). With these background data, we continued from 1985 onwards with predictions.

Regional P balances and soil P status

Regional characteristics of P balances and soil test P were studied by comparing three major agricultural areas in Finland (Fig. 1). Our primary data source was the Farm Statistic Yearbook for 2004 (Information Centre of the Ministry of Agricultural and Forestry, MMM Tike 2005). These data were complemented with data acquired from of the Information Centre of the Ministry of Agriculture and Forestry, the Uusimaa region Employment and Economic Development Centre (EEDC), and the Ostrobothnia region EEDC. For the third example region, Southwest Finland, the regional statistics compiled by Jaatinen (2005) was utilized as a complementary data source.

Agriculture of the Uusimaa region (around the capital town Helsinki) is characterized by grain production, with a relatively low and decreasing number of animal farms, less than 20% of the farmland being in their possession (Table 1). The Southwest Finland region (the regional centre is the town of Turku) differs from the previous one in that there are more animal farms, typically raising pigs and poultry (about 25–30% of the Finnish pig production takes place in Southwest Finland), and about a third of agricultural land belongs to the holdings of animal farms. The third region, Ostrobothnia (in the western central Finland, the regional centre is the town of Vaasa), has the highest density of animal farms of these three regions (their holdings covering 55% of the field area), dairy cows being the most important livestock animals. As a result, one third of the total agricultural land in Ostrobothnia is utilized as grassland, mainly for silage.

Complete regional P balances were not calculated, but the amount of P in animal manure in each region was estimated in the same manner as for the OECD balance sheet calculations, except for one point: we simplified the calculation of pig manure-P production by using the total number of pigs (instead of dividing the stock into 6 categories), with a coefficient 2.5 kg P animal^{-1} (instead of 2.6–5.95 in the OECD calculation) for the annual manure-P production. For the Southwest Finland region (with more pigs than in the two other regions), this simplified calculation gave P production in pig manure that was between the values calculated according to the OECD criteria (MTT, unpublished) and the national criteria used

Table 1. Characteristics of the three regions (see Fig. 1 for the regional centres) selected to represent different types of agricultural areas in Finland.

Regional centre	Uusimaa Helsinki	Southwest Finland Turku	Ostrobothnia Vaasa
Dominant soil types	clayey and fine silty soils	clayey and medium silty soils	organogenic soils, coarse silty and fine sandy soils
Major animals in the area (% of total livestock units in the area)[1]	bovine (46), pigs (30)	pigs (63), poultry (14)	bovine (43), pigs (31)
Animal density as livestock units relative to the total agricultural land, lu ha^{-1}	0.13	0.29	0.46
The share of agricultural land under possession of animal farms, %	19	30	55
The share of grassland of the total agricultural land, %	14	9	32
Manure-derived P relative to the total agricultural land, kg P ha^{-1}	2.5	7.8	15.3
Animal density in the farmland possessed by the animal farms, lu ha^{-1}	0.67	0.89	0.80
Manure-derived P relative to the area possessed by animal farms, kg P ha^{-1}	12	24	27
Manure-derived P relative to the potential manure spreading area[2], kg P ha^{-1}	10	22	24
(Thousands of hectares of additional manure spreading area in plant production farms)	(7)	(10)	(10)

[1] Data from 2004 (MMM Tike 2005); lu = livestock unit.

[2] Potential manure spreading area includes the land possessed by the animal farms, and the share of field area in plant producing farms for which payments based on manure spreading agreement took place during the year 2004 (for Uusimaa, data for payments was not obtained and the area given is the hectares for which this possibility was applied; annual manure amendments were made only on a part of these fields).

in the mid-term evaluation of the "Horizontal Rural Development Programme" (MMM 2004) that did not account for less than 20 kg piglets. A value of 0.14 was used when converting the number of pigs to livestock units.

The amount of P in animal manure was related to the total agricultural area in the region, and to the field area that was in 2004 under possession of animal farms (Ms. Anneli Partala, MMM Tike, personal communication). Because the plant production farms may use surplus manure from animal farms, the potential manure spreading area is larger than the area possessed by animal farms. Plant production farms have during the second Agri-Environmental Program received payments for using manure in their fields, and the acreage is documented by the regional Employment and Economic Development Centres. The size of this field area in 2004 in each of the three regions was also taken into account, and manure P was related to the whole potential spreading area (field area of animal farms and the additional manure spreading area).

The distributions of soil test P in the three regions were recalculated from the data collected for the mid-term evaluation of the "Horizontal

Rural Development Programme" (MMM 2004), by sorting by zip codes so that the soil analysis results matched the regions of agricultural census (MMM Tike 2005).

Soil test P and farm type

Soil test P concentrations in different types of farms were summarized by reanalyzing the data from farmer interviews performed during the follow-up study of the Agri-Environmental Program. The material is presented in more detail, with discussion on other aspects, by Palva et al. (2001), Pyykkönen et al. (2004), and Mattila et al. (2007). The material consisted of soil P_{Ac} concentrations of about 3300 fields in six catchments (so-called MYTVAS catchments) of rivers Lepsämänjoki, Lestijoki, Löytäneenoja, Savijoki, Taipaleenjoki and Yläneenjoki (Fig. 1). The soil P analyses were from the period between 1996 and 2002, and presented a summed field area of about 10 500 hectares. For our analysis, the material was grouped by farm types into four categories: cereal production (46% of the summed acreage) dairy production (32%), other plant production (potato, legumes, vegetables, etc.; 10%), and other animal production (pigs, poultry, beef, etc.; 12%).

Results and discussion

Trends in phosphorus use until 1995

Fertilizing infertile soils (e.g., soils reclaimed for agriculture, without nutrient application history) is a prerequisite for economic and sustainable production of field crops (Syvälahti 1970). An initial build-up of soil P status benefits plant growth by enhancing accessibility to plant roots of P that is dispersed in a larger soil volume than just fertilizer rows or the spots of applied manure. However, after a longer time of surplus P rates and an increase in plant-available P stock in a soil, yield responses to annual P applications become smaller and finally cease (see Saarela et al. 2006a, b). Then, surplus P applications are not beneficial anymore, but the yield level can be maintained by balanced P inputs, or P inputs can be withheld for a period of time.

In Finland, studies on P fertilization with variable superphosphate rates were started in 1930's. In these early experiments, with 275 yields (80% of which were grass) harvested during 1931–1954, Salonen and Tainio (1957) established a 58-% average increase in herbage yield when annual P application rate was increased from zero to 12–16 kg P ha^{-1} (27–36 kg P_2O_5 ha^{-1}). Doubling the P applications from the level of 12–16 kg P ha^{-1} to 24–32 kg P ha^{-1} further increased the yields by just 5% on average, and the authors concluded that the lower amount applied (12–14 kg P ha^{-1}) had been a sufficient annual P rate. Nevertheless, during the 1960's and 1970's, recommended annual P applications were as high as 30–60 kg P ha^{-1} (Salonen 1966, Jaakkola 1974). Fertilizer P use more than doubled from 1958 to 1975 (Laturi 1977), and peaked in the mid-1970's when the average fertilizer P sales corresponded to 35 kg P ha^{-1} (see Yli-Halla et al. 2001).

In the 1970's and 1980's, the link between surplus nutrient applications, nutrient transport from agricultural soils, and eutrophication of surface waters became a topic in the environmental debate (Nelson 1972, Schindler 1977, Kauppi 1984). Meanwhile, fertilizer P recommendations were adjusted downwards; for example, in 1984 P recommendation was 40 kg P ha^{-1} for cereals grown on a soil with a "fair" P status, but in 1991 it was lowered to 30 kg P ha^{-1} (Yli-Halla et al. 2001). As shown in Fig. 2, there was a big turn and a distinct drop in the fertilizer P sales in the beginning of the 1990's. At that time, the average annual P balance decreased from above +30 kg ha^{-1} in 1985–1990 to about +20 kg ha^{-1}, and the share of fertilizer P of the (estimated) total P use decreased from about 75% to about 65%. The big change in P use in the beginning of the 1990's was a combined effect of renewed P recommendations, a consequent decrease in P content of NPK compound fertilizers, an environmental tax on fertilizer P, and an obligation to keep a certain share (at least 15%) of the field area in each farm as set-aside (e.g. green fallow).

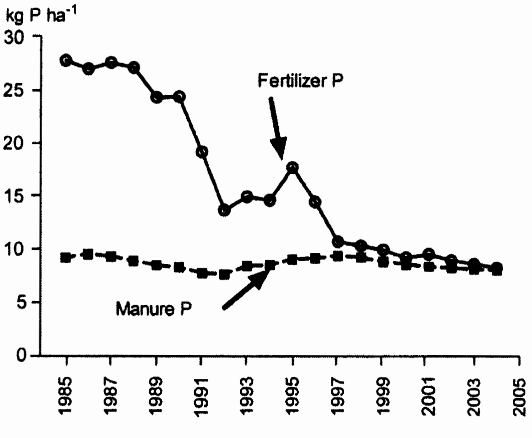

Fig. 2. Phosphorus in manure and fertilizer P sales during 1985–2005 (data from OECD balance sheet calculations).

In a review of the earlier studies on the P status of agricultural soils of Finland, Saarela (2002) estimated that starting from the 1930's, as much as 800–900 kg of P ha^{-1} had accumulated in the cultivated topsoils, adding at least one third to the total P content of the plough layer. In a much shorter period, from the early 1960's to the late 1970's, the average concentration of easily soluble P in the plough layer of the agricultural soils of Finland doubled, from 5 to about 10 mg P_{Ac} l^{-1} (Kähäri et al. 1987). From the late 1970's onwards, the P_{Ac} concentration of the Finnish agricultural soils continued to rise into the 1990's, but at a comparably moderate pace (Fig. 3).

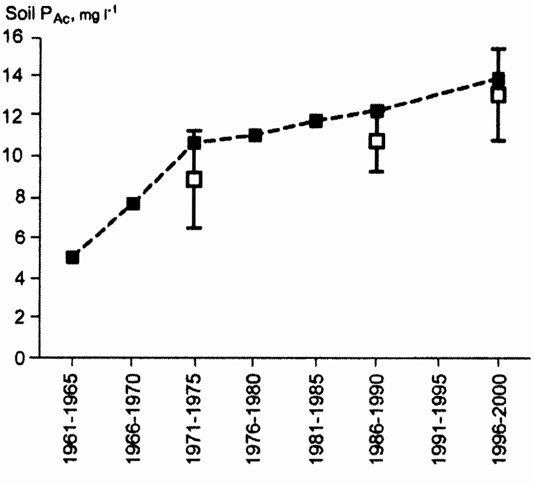

Fig. 3. Soil test P (P_{Ac}, acid ammonium acetate) concentrations during the last part of the 20th century in two different data sets: Kähäri et al. (1987) with black connected markers, and Mäkelä-Kurtto and Sippola (2002) with white markers (error bars show the standard error).

In addition to the large data on voluntary soil testing reported by Kähäri et al. (1987), complementary data on the nutrient status of the Finnish agricultural soils has been collected by Mäkelä-Kurtto and Sippola (2002). The latter material originates from about 700 fields that have been sampled in three occasions with 10–15-yr intervals. As shown in Fig. 3, the increase in soil test P from the 1970's agrees well in these two independent datasets.

Phosphorus use during the Agri-Environmental Programs

The decline in fertilizer P sales, as a result of lower P recommendations, and the consequent decrease in P surpluses since the late 1980's have been substantial, and in line with the trends in the other EU countries (see Withers et al. 2001, EEA 2005). As an example, in 1991 (before the first program period) the Finnish P recommendation for cereals grown on a soil with a "fair" P status was 30 kg P ha^{-1}, as compared to 20–28 kg P ha^{-1} after 1995. The average annual P surplus consequently decreased from above +25 kg ha^{-1} in 1985–1990 to around +12 kg P ha^{-1} in 1997–1999 (see also Antikainen et al. 2005). At present (from the start of the 2000's), national-level P balance has according to the OECD nutrient balance sheet calculations stabilized to less than +10 kg P ha^{-1}. Inorganic fertilizer P makes up a half of the total P use (see Fig. 2). For the third program period (2007–2013) P application limits have been once more updated such that, for example, for barley grown on a soil with a "fair" P status, a P rate of 22 kg P ha^{-1} is allowed in mineral fertilizers (MMM 2007).

According to Saarela et al. (2006a, b), balanced P additions would keep crop yield levels at approximate maximum when soil test P concentrations are at 5–7 mg P_{Ac} l^{-1} in clayey soils, or at 10–12 mg P_{Ac} l^{-1} in mineral soils with coarser texture than clay. Because the average and median P_{Ac} concentrations of the agricultural soils of Finland are above these limits (MMM 2004, average P_{Ac} was 12.4 mg l^{-1} in 1997–2002), further decreasing P surpluses would not jeopardize plant production potential. In most cases yield responses to annually added P are very small, and fertilizer P applied in surplus rates is nothing but an expense to the farmer, especially as the effect on quality parameters of grain yields are highly uncertain (see Salo et al. 2007). Also, lowered recommendations for P supplements to dairy cows (see MTT 2006) and thus lower P content in dairy manure will decrease P balances. It should be noted, however, that the P application rates allowed in the third Agri-Environmental Program (2007–2013, MMM 2007) are much higher than annual P uptake for those soils that have a relatively low P status.

Soil test P concentrations during the Agri-Environmental Programs

National-scale trend

According to the data of commercial soil testing, the average soil test P concentration has stabilized at a level of 12–13 mg P_{Ac} l^{-1}. The concentrations appear to have changed very little during the Agri-Environmental Programs, and there's a good agreement between different datasets. In the large material of the mid-term evaluation of the "Horizontal Rural Development Programme" (MMM 2004), the average soil test P concentration of 1997–2002 analyses was 12.4 mg P_{Ac} l^{-1}, which agrees with the average concentration of 13 mg P_{Ac} l^{-1} in the sample of 700 fields in 1998 of Mäkelä-Kurtto and Sippola (2002). For the 583 000 samples analyzed by Viljavuuspalvelu Oy/Soil Analysis Service between 2001–2005, the mean P_{Ac} concentration was 12.6 mg l^{-1}. The relative difference between these different data sources is only 4–6%.

When discussing the recent soil test P data and the earlier summaries of commercial soil tests (e.g. those in Fig. 3), it is important to note that as a result of the introduction of the first Agri-Environmental Program in 1995 and a requirement to analyze soil P in the farms that participate, the number of agronomic soil tests more than doubled in a few years after 1995. A large number of soils were tested perhaps for the first time ever, and there was a shift from one sampling population to a different one; this was indicated by a sudden rise in the average soil test P concentration and a sudden drop in the average pH of the soils analyzed in 1995–1997 (Yli-Halla et al. 2001). The increase in sampling frequency probably resulted in more accurate estimates of nutrient status of the agricultural soils of Finland, but one should keep in mind that the post-1995 data doesn't represent the same population as compared to the pre-1995 data. From the latter part of the 1990's, farmers also started to take the samples mostly by themselves, with possibly less accurate sampling protocols than before when sampling was predominantly done by the agricultural advisers.

Soil test P of 1600 fields in 1997 vs. 2002

To study the changes in soil test P concentrations during the Agri-Environmental Programs, a sample of 1600 fields was extracted out of the databases of Viljavuuspalvelu Oy/Soil Analysis Service in 2003. These data represent soil test P concentrations in the same fields in 1997 and 2002 (Fig. 4). The median and mean values for 1997 analyses were 11 and 12.5 mg P_{Ac} l^{-1}, respectively (95% confidence interval of the mean 12.1–12.9 mg P_{Ac} l^{-1}), which were higher than the median and mean for the later testing in year 2002, 9 and 11.4 mg P_{Ac} l^{-1}, respectively (95% C.I. of the mean 10.9–11.8 mg P_{Ac} l^{-1}). Medians differed from each other ($p < 0.0001$, Wilcoxon signed rank test) and the confidence intervals for mean values did not overlap; hence, the decline in this material can be regarded as real. This is the first larger data that show a declining trend in soil test P, that was already anticipated after the first Agri-Environmental Program (Yli-Halla et al. 2001). We don't know how this sample represents different types of farms, but the distribution of these results suggests that it was mostly from fields under cereals. In this sample, the following quartiles were calculated for the 2002 results: $Q_{25} = 6.0$, $Q_{50} = 9.0$, and $Q_{75} = 14$ mg P_{Ac} l^{-1}, which is a distribution typical for a group of cereal-producing farms (discussed later on).

Model calculations

We also carried out a modelling exercise to estimate the changes in P status in a typical Finnish field if cropping is done with the current average P balance. We started the model run with a hindcast, by applying the soil test P and P balance data of 1985 as inputs. The results (Fig. 5) suggested a similar pace of P_{Ac} increase from 1985 to 1995 as was the mean change in the datasets of Kähäri et al. (1987), and Mäkelä-Kurtto and Sippola (2002), that is, about one unit increase in the average soil P_{Ac} concentration in 10 years. The model results further suggested that soil P_{Ac} concentrations would have peaked in 1995–1997, and that they would be slowly decreasing as far as soil P balance remains less than +10 kg P ha^{-1} yr^{-1}. Because of "aging" of P in soils (see Sillanpää 1961, Chardon and Blaauw 1998), i.e., slow migration of P from surfaces of P-sorption components (mainly Al- and Fe-oxides/hydroxides) deeper in their mineral structure, the concentration of easily soluble P (soil P_{Ac} concentration) may decrease despite the P balances show small surpluses.

In an earlier work, Yli-Halla et al. (2001) used the ICECREAM model (the Finnish version of the CREAMS/GLEAMS model, see Tattari et al. 2001, Yli-Halla et al. 2005) to assess the changes in soil test P in individual soils as a result of renewed fertilizer recommendations of the first Agri-Environmental Program. In their simulations, the most common levels of soil test P concentrations were at a steady state when (barley) grain yield was 3000 kg ha^{-1} and the annual P rate was 15 kg ha^{-1}. Considering that the grain yields recorded in the agricultural census typically are between 3000 and 3500 kg ha^{-1} (MMM Tike 2005) and that 15 kg ha^{-1} fertilizer P is a typical application rate (see Palva et al. 2001, Pyykkönen et al. 2004), a small decrease in average soil test P could have taken place during the two programme periods (1995–2006). However, a big change in average soil test P is not probable with surplus P balances and because of the fact that soil test P concentrations change slowly, unless they are initially at a very high level (Yli-Halla et al. 2002).

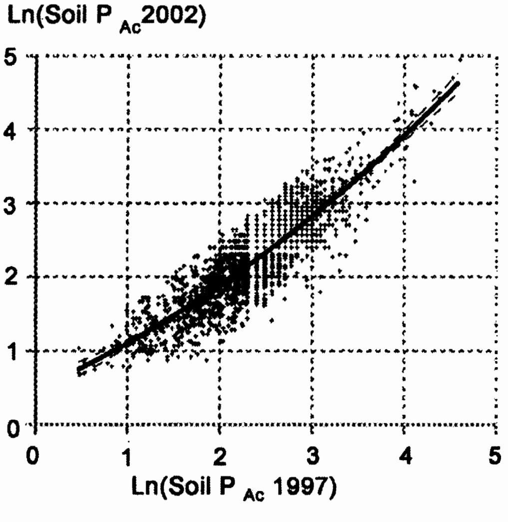

Fig. 4. A sample of soil test P concentrations (transformed to natural logarithm) including about 1600 agricultural soils that were analyzed in 2002 at Viljavuuspalvelu Oy, and the result of the previous soil testing (in 1997) of the same soils.

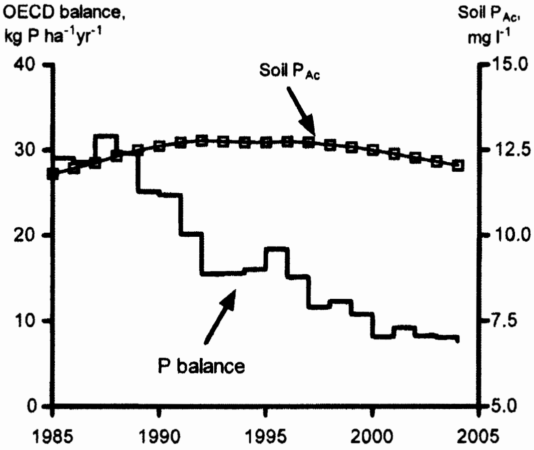

Fig. 5. The average P balance in the Finnish agriculture (staircase line; OECD nutrient balance sheet calculations) and the modelled soil test P (P_{Ac}, acid ammonium acetate) concentrations (connected markers); note the narrow scale of the right-hand (soil P_{Ac}) y-axis. The P balances were used as input to the soil P_{Ac} model (Ekholm et al. 2005); as a start-point P_{Ac} in 1984, a value of 11.8 mg P_{Ac} l^{-1} was used (Kähäri et al. 1987).

Regional scale P balances and soil test P – data from three example regions

According to a recent (1995–1999) P flow analysis of the Finnish agriculture (Antikainen et al. 2005), 70% of the P that was removed from the soil in plant products ended up in animal feed and, further, mostly in animal manure. Because manure P is in a key position when a trend in soil P is concerned, it is emphasized in the following discussion.

From the agricultural census, we calculated estimates for manure P inputs for the three regions described above (Table 1). The estimates include (i) manure P input relative to the total field area in a region, (ii) manure P input relative to the field area in animal farms within a region (i.e., when no manure is exported from the animal farms), and finally (iii) manure P input relative to the potential manure spreading area that includes the acreage of the animal farms and the additional area in plant producing farms that in 2004 had a commitment for manure import. To estimate a balanced P input for a field hectare, we assumed that annual P removal of the harvested part of cereal yields would be around 10–15 kg P ha^{-1}, whereas grassland harvest would collect about 21–26 kg P ha^{-1} from the soil (Saarela et al. 1995, Turtola and Kemppainen 1998).

Because the maximum allowed P applications are based on agronomic soil test results (MMM 2007), the above estimates are discussed in the context of soil test P concentrations in the three example regions. Soil test data are based on analyses done during 1997–2002 by three commercial soil test laboratories (Viljavuuspalvelu Oy/Soil Analysis Service, Ympäristöpalvelu Oy/

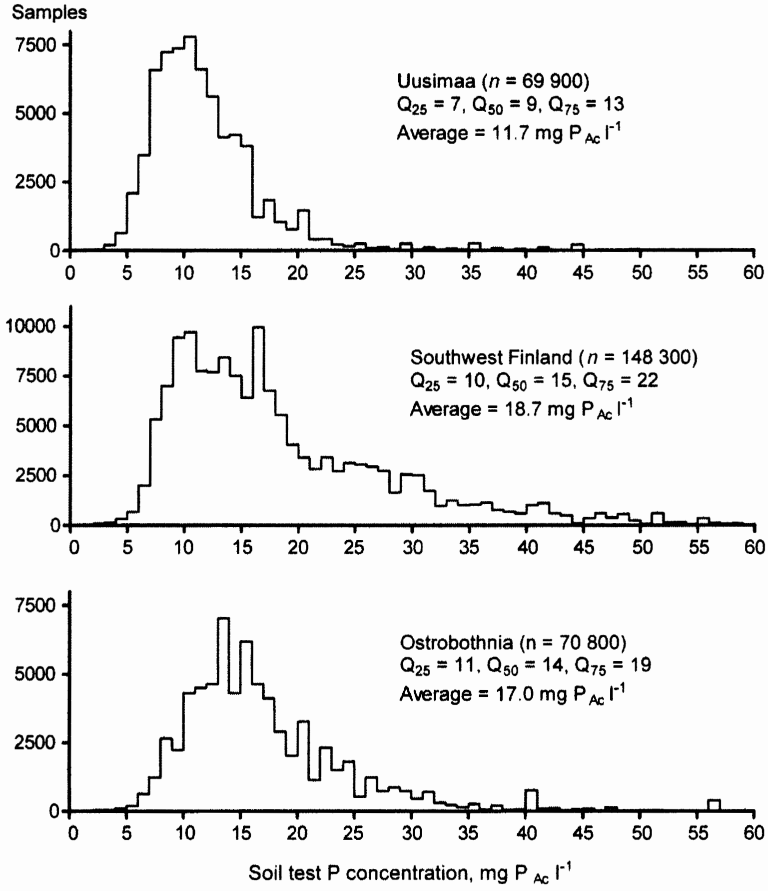

Fig. 6. Soil test P distributions, with quartiles and average concentrations, of the three example regions characterized in Table 1 (results of commercial soil tests performed during 1997–2002, MMM 2004).

Environmental Service, and Sokerijuurikkaan tutkimuskeskus/Sugarbeet Research Institute), and summarized in Fig. 6.

In the Uusimaa region, cereal production is dominating and manure P inputs to the total land area remain low (Table 1, Fig. 7). It is not surprising that when fertilizing is carried out with mineral P, and surplus P rates are not economical (except when soil P_{Ac} concentrations are very low), soil test P concentrations are modest (Fig. 6). Even then, only 9% of the samples of the Uusimaa region had P_{Ac} concentration lower than 7 mg l^{-1}, which means that few soils (clayey soils made up 56% of the samples from Uusimaa) are expected to give yield responses upon annual P applications in surplus rates (Saarela et al. 2006a).

In Southwest Finland, intensive pig and poultry production takes place, and P is imported to the animal farms in feed and concentrates. Thus, P surpluses are evident in animal farms of Southwest Finland (Table 1). In addition, non-cereal crops (sugar beet, vegetables, potato, etc.) are also important in this region. Because fertilizer P cost is small in relation to the value of e.g. vegetable

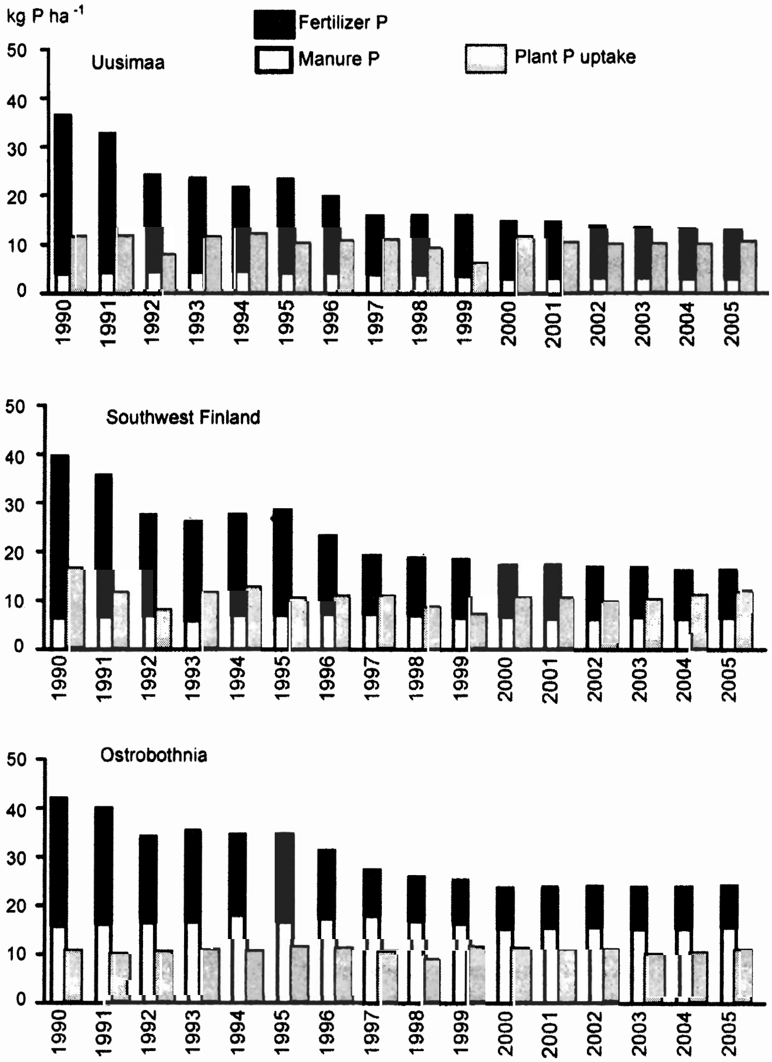

Fig. 7. P inputs as manure and fertilizer P and estimated plant P uptake in the three example areas (regionalized OECD balance sheet calculations).

yields, P balances and soil test P levels tend to be high in the production of high value crops. Very high P rates are continuously allowed in the production of many non-cereal crops, even in the third Agri-Environmental Program (MMM 2007). Fertilizer P trial data are lacking for most of the high value crops, and it may be that P fertilization of these crops is well above the yield-limiting level.

Even though the regional-scale annual P surpluses (Fig. 7) have been decreasing slowly in the recent years, surpluses are nevertheless unnecessary when considering the soil P status. The soil P_{Ac} data of Southwest Finland presented in Fig. 6 agrees with the earlier observation of Yli-Halla et al. (2001) in that the frequency of "high" and "excessive" P status is higher in Southwest Finland than elsewhere in the country. In cereal production, extremely few soils in this region would actually benefit of annual surplus P applications (or annual P applications in general), as the proportion on the soils that tested lower than 7 mg P_{Ac} l^{-1} was only 2%.

In practice, when P application rate is based on agronomic soil test results (MMM 2007), the combination of high soil P_{Ac} and abundant manure means that in Southwest Finland animal manure alone would be enough to satisfy the P need of the whole agricultural land if grown with cereals. However, little manure was in 2004 exported outside the animal farms in Southwest Finland (as well as in Uusimaa). The share of agricultural land utilized as additional manure spreading area in plant producing farms was just 5–6% in Southwest Finland (as compared to 13% in Ostrobothnia). In the farms that are committed to the third Agri-Environmental Program, maximum allowed P rates in mineral fertilizers can be surplus amounts only for those soils that test "low" or "fair" in P, and balanced P rates are allowed for the soils with P status that is considered "satisfactory". Hence, the situation in Southwest Finland is far from sustainable, calling for a marked increase in the area available for manure spreading in plant production farms. However, the Agri-Environmental Program includes exceptions for the spreading of animal manure: for cereals 18 kg ha yr^{-1} and for grass crops 24–35 kg ha yr^{-1} total P in manure is allowed unless soil P status is classified as "excessive". If nutrient balances show large surpluses, as they often do in areas with a high density of animal farms (see Sharpley 1999, Tamminga 2003), long-term effects on individual fields include even saturation of soils with P (see Kingery et al. 1994, Novak et al. 2000, Uusitalo et al. 2007b).

The soil test P distribution of the Ostrobothnian region was intermediate between the two other regions (Fig. 6), the median and mean P_{Ac} being closer to the soils of Southwest Finland than to those of Uusimaa. Soil texture in this region is typically coarser than clay (74% of the samples in our material were coarse-textured mineral soils), and according to Saarela et al. (2006b) annual P applications may in soils with coarser textures give small yield response when P_{Ac} concentrations are 10–12 mg l^{-1} or lower. Based on the criteria of Saarela et al. (2006b), 10–15% of Ostrobothnian soils could give 3% or higher yield response to surplus P applications.

In the Ostrobothnian region, the amount of P in animal manure appears to be clearly higher than the estimated plant P uptake, and the regional P balances show very high surpluses (Fig. 7). There should thus be no need to import mineral fertilizer P into the region. However, it seems that in Ostrobothnia fertilizer P import to the average field hectare, at level of 8.2–8.4 kg ha^{-1} during 2001–2005, is remaining constant. At the same time in Uusimaa and Southwest Finland, fertilizer P use has decreased by a kilogram from the 2001 level of 10.5–10.8 kg ha^{-1}.

Soil test P in different types of farms

In the above discussion, we assumed that soil test P concentrations of animal farms are, due to past higher P balances, higher than those of plant production farms. To find out whether this is actually true, we reanalyzed the data obtained from farmer interviews performed during the follow-up study of the second Agri-Environmental Program (Pyykkönen et al. 2004, Mattila et al. 2007).

The lowest median and average soil test P concentrations in these data were found in the group of cereal farms, whereas the farms specialized in other plant production (sugar beet, vegetables, potato, etc.) had the highest soil test P (Table 2). The animal farms were between these extremes. The typical P_{Ac} concentrations were higher in dairy farms than in cereal farms, but the distributions of soil test results were similar in these two groups. The group "Other plant production" (sugar beet, vegetable, potato, etc.) differed from the others not only in that the median P_{Ac} concentration was high (about 19 mg P_{Ac} l^{-1}) but also in that the distribution was much wider than in the other farms. In turn, for the "Other animal" (primarily pigs or poultry) farms, median P_{Ac} concentration of 15 mg l^{-1} was recorded and the width of the interquartile range was the second widest (Table 2). For all of the groups, the distributions of soil P_{Ac} were positively skewed, thus tailing toward high concentrations, and averages for the groups were clearly higher than the medians. Hence, in all groups there were fields that had been heavily fertilized or manured, whereas a larger fraction had obviously received more moderate P dressings.

During the last ten years, the number of livestock farms decreased by 50% in Finland, whereas the number of animals has remained at a relatively constant level. Thus, unit size and production intensity of livestock farms have increased (Lehtonen and Pyykkönen 2005), following the general trend in EU countries (see Withers et al. 2001, EEA 2005). Livestock production also appears to be growing in those areas that already have similar type of production (e.g., dairy farms in Ostrobothnia region, pig and poultry production in Southwest Finland region). According to Lehtonen and Pyykkönen (2005), the trend of regional specialization of the Finnish livestock production would be continuing at least the decade ahead. Should the animal production intensity further increase in an area such as Southwest Finland, handling animal manure in a sustainable way will be a major future challenge.

Whereas farm-level nutrient balances for different kinds of animal production are undocumented, a study including 319 Finnish dairy farms was recently published by Virtanen and Nousiainen (2006). They calculated a mean P balance surplus of +12 kg ha^{-1}, and in their material P imports to an average farm included 9 kg P ha^{-1} as mineral fertilizes. Then, P surpluses in these farms could be reduced to some kilograms per hectare by omitting P fertilizers. In a model dairy farm of south England (with 1.6–1.9 cows ha^{-1}), Withers et al. (1999) showed how annual farm-level P surpluses could be reduced from +23 kg P ha^{-1} to only +3 kg P ha^{-1} by means of optimizing feed and fertilizer P imports, and the reduced P balance didn't affect the quality or quantity of milk and herbage production in the farm (for a similar experiment in the Netherlands, see Aarts et al. 2000). According

Table 2. Summary of soil test P (P_{Ac}) concentrations within the six MYTVAS catchments (Mattila et al. 2007) as grouped according to the main production types of farms.

	Cereal production	Other plant production	Dairy farms	Other animal production
Number of observations	1416	301	1217	390
	mg P_{Ac} l^{-1} soil			
Minimum	1.3	<1	<1	<1
25% Percentile	7.0	10.0	8.0	9.0
Median	9.5	18.5	11.9	15.0
75% Percentile	14.0	33.0	17.0	23.0
Maximum	260	150	171	130
Mean	12.2	24.7	15.3	19.3
Std. Error	0.29	1.2	0.42	0.87

to ongoing Finnish studies (prof. Pekka Huhtanen/MTT, personal communication), the same can be done in Finnish dairy farms. Reactions by the farmers' interest organisations concerning the maximum allowed P application rates justifying to environmental support of the third Agri-Environmental Program (covering 2007–2013, MMM 2007), with somewhat reduced maximum P rates as compared to the previous period (2000–2006), suggest that soil P status is high in many animal farms. Then, it would be crucial to optimize feed and fertilizer purchases, and minimize farmgate P balances, as has been done in the English and Dutch model farms.

In addition to P balances, production line of farms may otherwise affect the P losses. As an example, in dairy farms surface applications of P for grasslands are common practices. Turtola and Kemppainen (1998), and Turtola and Yli-Halla (1999), among others, have reported high concentrations and losses of dissolved P via surface runoff from grassland that received P dressings on soil surface (see also Withers et al. 2001). Because surface runoff volumes may be higher from grass leys than from annually tilled soils (see Turtola and Kemppainen 1998), a given P balance is probably associated with substantially higher levels of dissolved P in runoff from grasslands than from fields under annual crops.

Conclusions

During the last 50 years, soil test P concentrations of agricultural fields in Finland have been elevated, by surplus P applications, to a level at which yield responses to annually applied P are unlikely to occur. On most of the fields, surplus annual P applications are no longer agronomic necessities but only bring costs to those farmers who use mineral P fertilizers, and in all cases increase the potential for off-site P transport. The average P balance has decreased from +35 kg ha^{-1} in the late 1980's to +8 kg ha^{-1} in 2000–2004, and the increase in soil test P concentrations appears to have levelled out during the Agri-Environmental Programs. However, when P applications are generally done at surplus P rates, most of the Finnish farms still operate above the economic and environmental optimums. Also, P balances are not uniform across the different regions inside the country. Cereal (feed) and animal productions differentiate regionally, and further intensification of livestock production is anticipated in some regions. Those parts of the country that have high animal densities, typically have substantial P surpluses and higher than average soil P status. In these areas, agricultural P losses may increase in the future, unless P imports to farms are reduced by careful planning, and a substantial part of manure is exported to farms specialized in cereal production.

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SELOSTUS

Suomen maatalouden fosforitaseiden kehitys ja maan helppoliukoisen fosforin pitoisuus

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Pellon fosforitaseen suuri ylijäämä kasvattaa maan helppoliukoisen fosforin pitoisuutta, mikä puolestaan lisää pellolta poistuvien valumavesien fosforipitoisuutta. Maan fosforipitoisuus on siten yksi tärkeimmistä tekijöistä, jotka vaikuttavat maataloudesta peräisin olevaan vesistöjä rehevöittävään fosforikuormitukseen. Ensimmäisen ympäristöohjelmakauden (1995–1999) arviointiraportissa oletettiin uudistettujen lannoitussuositusten laskevan suomalaisten peltojen helppoliukoisen fosforin pitoisuutta ja esitettiin huoli fosforilannoituksen riittämättömyydestä sadon määrän ja laadun tason ylläpitämiseen. Keskimääräinen maatalousmaahan lisättävä fosforimäärä on kuitenkin vielä tänä päivänä 8 kg ha^{-1} suurempi kuin pelloilta sadon mukana korjattavan fosforin määrä. Vaikka maan helppoliukoisen fosforin pitoisuuden yleinen kasvu näyttäisi taittuneen vuoden 1995 jälkeen, maan fosforipitoisuudet pysyvät valtaosalla peltoalastamme vielä pitkän aikaa niin korkeina, ettei vuotuisella fosforilannoituksella yleensä saada mitattavaa sadonlisää. Tulevaisuudessa tavoitteena tulisi edelleenkin olla suhteellisesti eniten kuormittavien, fosforipitoisuudeltaan korkeiden lohkojen fosforipitoisuuksien alentaminen. Tämän lisäksi alhaisemmissa fosforiluokissa olevien peltojen lannoitus voidaan tehdä sadon fosforinottoa vastaavalla fosforimäärällä. Korkeita fosforipitoisuuksia näyttäisi olevan runsaimmin erikoiskasvien viljelyyn sekä sian- ja siipikarjantuotantoon keskittyneillä tiloilla. Fosforitaseiden ylijäämät ovat maitotiloillakin vielä korkeita, ja niitä tulisi alentaa ruokinnan suunnittelun keinoin ja vähentämällä väkilannoitefosforin käyttöä. Viljatiloilla peltojen fosforipitoisuudet ovat yleensä kohtuullisen alhaisia. Karjanlannan fosfori tulisi levittää erityisesti kasvinviljelytilojen fosforiköyhimmille peltolohkoille viljelykasvien tarpeen mukaisesti. Eri tuotantomuotojen alueellinen eriytyminen kuitenkin rajoittaa karjanlannan käytön tehostamista. Jos eläinten rehuseosten fosforipitoisuudet eivät laske nykyisestä, eikä lannan sisältämää fosforia levitetä olennaisesti nykyistä laajemmalle alueelle, peltomaiden fosforipitoisuudet ja maataloudesta peräisin oleva fosforikuormitus eivät todennäköisesti vähene karjatalouden keskittymäalueilla.