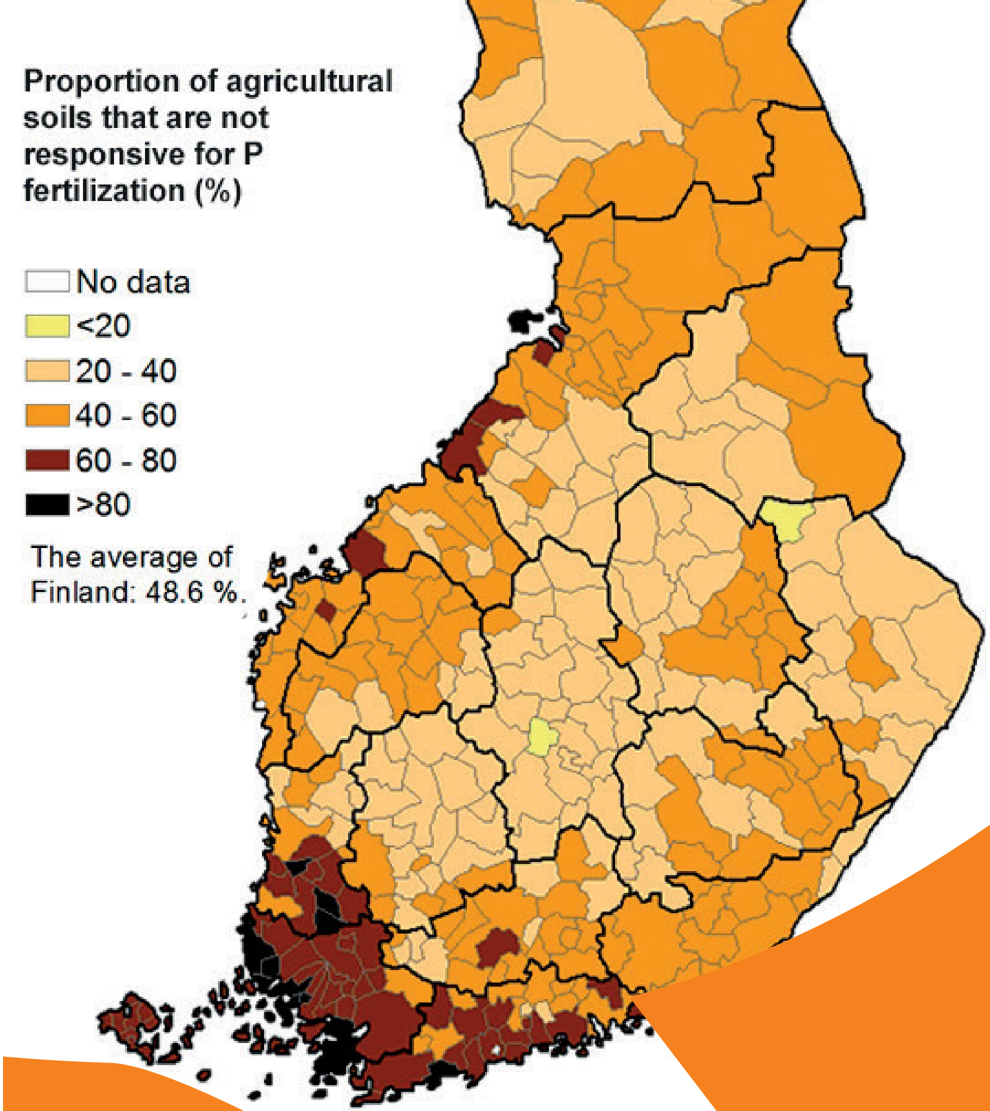

Natural resources and bioeconomy studies 62/2015

Regional P stocks in soil and in animal manure as compared to P requirement of plants in Finland

Kari Ylivainio, Minna Sarvi, Riitta Lemola, Risto Uusitalo and Eila Turtola

NATURAL RESOURCES INSTITUTE FINLAND

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Baltic Forum for Innovative Technologies for Sustainable Manure Management. WP4 Standardisation of manure types with focus on phosphorus

Kari Ylivainio, Minna Sarvi, Riitta Lemola, Risto Uusitalo and Eila Turtola

Natural Resources Institute (Luke) is a research and development organization established in 2015 by merging MTT Agrifood Research Finland, the Finnish Forest Research Institute (Metla), the Finnish Game and Fisheries Research Institute (RKTL) and the statistical services of the information Centre of the Ministry of Agriculture and Forestry (Tike). This report was published in 2014 by MTT Agrifood Research Finland, http://www.mtt.fi/mttraportti/pdf/mttraportti124.pdf, and this is a reprint of that version.

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Abstract

Kari Ylivainio, Minna Sarvi, Riitta Lemola, Risto Uusitalo and Eila Turtola

Natural Resources Institute Finland, FI-31600 Jokioinen, firsname.lastame@luke.fi

Phosphorus (P) is an essential plant nutrient and sufficient availability is sustained by soil reserves and fertilization. On the other hand, P leaching from agricultural fields causes eutrophication of the surface waters. Therefore, soil P levels and P fertilization should be adjusted according to plant need to minimize P leaching.

In this study we evaluated P requirement of plant production (cereals and grasses) at a municipality level to reach 95 % of the maximum yields. Soil test P (STP; acid ammonium acetate, pH 4.65) and content of P in manures were taken into account when estimating the regional P stocks and comparing them to the requirement for P fertilization. STP values originated from soil samples (total of 1 008 302 samples) taken by farmers from their own fields and analyzed at the soil testing laboratories in 2005-2009. These samples represent cultivated field area (92 %) that is participating in Finnish Agri-Environmental Program. Numbers of the production animals within the municipalities were obtained from the Information Centre of the Ministry of Agriculture and Forestry (TIKE), The Finnish trotting and breeding association, Saga Furs Oyj and Kopenhagen Fur. Information of the total amount of P excreted into the manure was estimated according to the feeding trials conducted at MTT Agrifood Research Finland.

Average STP value for the cultivated soils was 13.0 mg l^{-1} and for clay, coarser textured mineral and organic soils the average STP values were 12.3, 13.9 and 9.8 mg l^{-1}, respectively. About half of the fields (49 %) had such a high STP value that P fertilization is unlikely to provide yield response. Least responsive soils for P fertilization were clay (69 % were nonresponsive), followed by coarse textured mineral soils (47 %) and organic soils (14 %). In the regional level, the shares of nonresponsive fields for P fertilization were highest in Southwest Finland (73 %) and in Åland (76 %).

Content of P in animal manures in Finland was 17.5 million kg in 2011, originating mainly from cattle (9.8 million kg), pigs (3.6), fur animals (1.8) and poultry (1.5). Most of the manure P was produced in the Ostrobothnia region (42 %). Manure P equaled to 8.8 kg ha^{-1}, if spread evenly across all cultivated fields (excluding fallow) in Finland, whereas the P requirement of plants was 8.6 kg ha^{-1}. However, in addition to manure P, 5.6 kg ha^{-1} of mineral P fertilizer was sold in 2011.

To depress the loading potential, P fertilization should be adjusted according to plant requirement, which would lower high STP values. At the moment manure P content would be enough for plant P requirement, with no need for mineral P fertilizer, if manure could be spread to areas with actual need for P. However, this will require novel methods for manure processing to make P transportation economically viable. Moreover, current Finnish legislation allows P use that is not optimal from the view of neither plant production nor the environment.

Keywords:
Manure, *phosphorus fertilization*, P-index, soil test P, the Baltic Sea, yield response

Tiivistelmä

Kari Ylivainio, Minna Sarvi, Riitta Lemola, Risto Uusitalo ja Eila Turtola

Luonnonvarakeskus, 31600 Jokioinen, etunimi.sukunimi@luke.fi

Fosfori on välttämätön kasvinravinne, jonka saatavuus riippuu mm. maan helppoliukoisen fosforin pitoisuudesta ja fosforilannoituksesta. Fosforilannoitus ja maan helppoliukoinen fosfori vaikuttavat myös fosforin huuhtoutumisriskiin. Fosforihuuhtoumien minimoimiseksi fosforilannoitus tulisi tarkentaa kasvien tarpeen mukaiseksi.

Tässä tutkimuksessa selvitettiin alueellinen fosforilannoitustarve pyrittäessä 95 %:iin maksimisadosta ja huomioiden maassa olevat fosforireservit (viljavuusuuttoinen fosfori) sekä kunnassa muodostuva lantafosforin määrä. Peltolohkojen viljavuusanalyysitiedot koostuivat viljelijöiden vuosina 2005-2009 ottamista ja viljavuuslaboratorioiden analysoimista maanäytteistä (1 008 302 maanäytettä). Kuntakohtaiset eläinmäärät toimittivat Tilastokeskus (TIKE), Suomen Hippos ry, Saga Furs Oyj ja Kopenhagen Fur. Eläinten lannan sisältämä fosforimäärä arvioitiin perustuen MTT:n ruokintakokeisiin.

Suomalaisten peltolohkojen keskimääräinen fosforiluku oli 13,0 mg l^{-1}. Maalajeittain ryhmiteltynä vastaavat fosforiluvut savimailla, karkeammilla kivennäismailla ja orgaanisilla mailla olivat 12,3, 13,9 ja 9,8 mg l^{-1}. Noin puolessa analysoiduista maanäytteistä (49 %) fosforin saatavuus ei ollut kasvin kasvua rajoittava tekijä, toisin sanoen näillä mailla ei ole fosforilannoitusvastetta viljaa tai nurmea viljeltäessä. Maalajeittain tarkasteltuna vastaavat osuudet savimaille, karkeammille kivennäismaille ja orgaanisille maille olivat 69, 47 ja 14 %. Manner-Suomen ELY-keskuksista Varsinais-Suomen alueella on eniten peltolohkoja (73 %), missä fosfori-lannoituksella ei saada satovastetta. Ahvenanmaalla vastaava osuus on 76 %.

Kotieläinlannan sisältämä fosforimäärä oli 17,5 milj. kg vuonna 2011, koostuen pääasiassa naudan- (9,8 milj. kg), sian- (3,6), turkiseläin- (1,8) ja kananlannasta (1,5). Suurin osa lantafosforista (42 %) muodostui Pohjanmaalla. Lantafosforia riittäisi viljellylle peltopinta-alalle tasaisesti levitettynä 8,8 kg ha^{-1}, kun koko lannoitustarve on 8,6 kg ha^{-1}. Lantafosforin lisäksi väkilannoitefosforia käytettiin 5,6 kg ha^{-1} vuonna 2011.

Koska peltojen fosforiluvulla on merkittävä vaikutus fosforin huuhtoutumispotentiaaliin, olisi fosforilannoitus säädettävä kasvien tarpeen mukaiseksi. Näin voitaisiin aikaa myöten alentaa maan fosforilukuja ja vähentää fosforin huuhtoutumista. Tällä hetkellä lantafosforilla voitaisiinkin korvata väkilannoitefosforin käyttö kokonaan. Tämä vaatii kuitenkin lantafosforin kuljettamista kauemmaksi lannan syntysijoilta, mikä ei nykyisillä tekniikoilla ja hintasuhteilla ole taloudellisesti kannattavaa. Myös ympäristölainsäädäntö sallii nykymuotoisen fosforin käytön.

Avainsanat:
Fosfori-indeksi, fosforilannoitus, fosforilannoitustarve, Itämeri, lantafosfori, satovaste, viljavuusuuttoinen fosfori

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1. Introduction

Phosphorus (P) is a finite natural resource, and it is estimated that known, easily exploitable P resources will be depleted within 50-100 years (Cordell et al. 2009). Because most of the mined P (82 %) is used for fertilizer production, this will gradually increase prices of P fertilizers and draw attention to more efficient utilization of P reserves. In Finland, after the 2nd World War, the use of mineral P fertilizers increased (Fig. 1), peaking in 1975 when agricultural soils were amended annually with 34.2 kg P ha^{-1}. Since then, the use of mineral P fertilizers has decreased to present amount of 5.4 kg ha^{-1} in 2012 (Information Centre of the Ministry of Agriculture and Forestry 2012). In addition to the economical consideration, awareness of the consequences of P transport from soil to water bodies has drawn attention to adjust P use and P fertilization recommendations to an environmentally sound level.

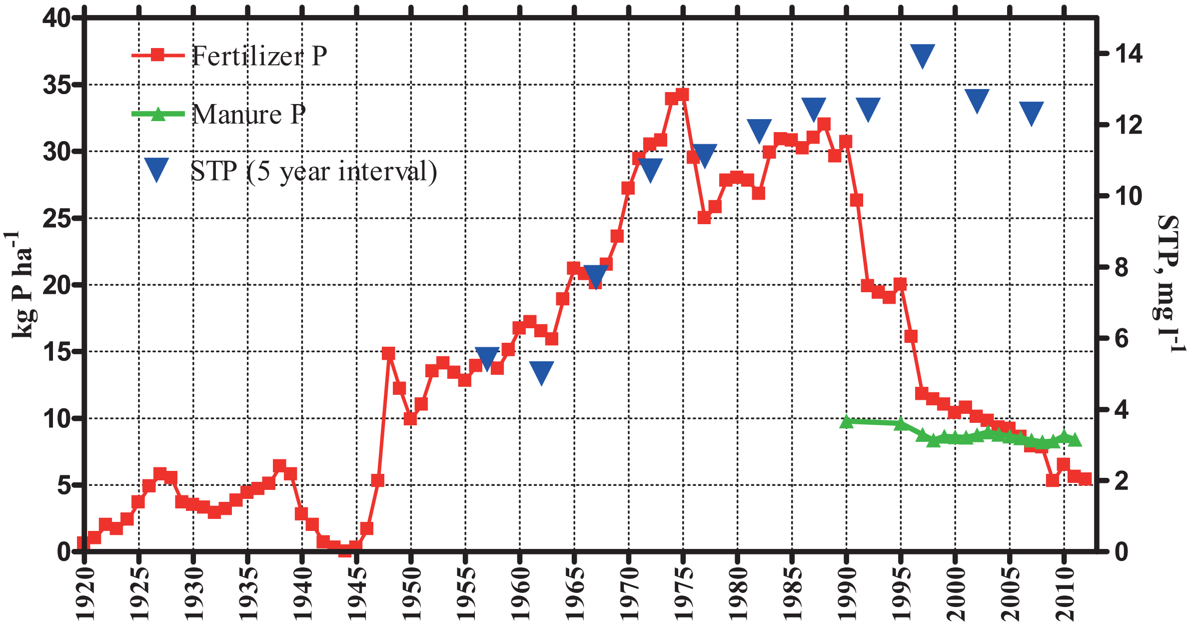


Figure 1. Sales of mineral P fertilizers to farms in Finland between 1920 and 2011 (Kekäläinen 1999, Information Centre of the Ministry of Agriculture and Forestry 2012) and production of manure P between 1990-2011 (Aakkula et al. 2010, Tapio Salo, personal communication). Development of average STP value, representing easily soluble P in the plough layer of cultivated soils, at intervals of five years during 1955-2010, is shown according to data of Viljavuuspalvelu Oy (Kurki 1963, Kurki 1972, Kurki 1982, Kähäri et al. 1987, Mäntylahti 2002, Tuloslaari 17.10.2012 http://www.tuloslaari.fi/index.php?id=41).

In Finland the official method for analyzing soil test P (STP) value is an acid ammonium acetate extraction (P_{aaac}, 0.5 M acetic acid + 0.5 M ammonium acetate solution, pH 4.65), which was introduced in the 1950’s (Vuorinen and Mäkitie 1955). STP values are classified into seven categories according to the P concentration and each class is further divided according to organic matter content of the soil (Table 1). Phosphorus fertilization recommendations are based on these categories.

Table 1. The Finnish soil P classification system (Viljavuuspalvelu 1998, ref. Peltovuori 1999).

Texture	OM, %	STP class 1	2	3	4	5	6	7
		mg P l^{-1} soil						
Clay soils	< 3.0		2.0	4.0	8.0	15	25	40
heavy clay, sandy & silty clay, clay	3.0 – 5.9		2.0	3.5	7.0	14	23	40
loam	6.0 – 19.9		1.5	3.0	6.0	12	20	40
Coarse mineral soils:	< 3.0		3.0	7.0	13	22	35	50
silt, loam, sand	3.0 – 5.9		3.0	6.0	12	20	33	50
	6.0 – 19.9		2.5	5.0	10	18	30	50
Coarse mineral soils:	< 3.0		2.5	5.0	10	18	30	50
fine and very fine sand, till	3.0 – 5.9		2.5	4.5	9.0	17	28	50
	6.0 – 19.9		2.0	4.0	8.0	15	25	50
Organic soils (Sphagnum peat excluded)			2.0	4.0	8.0	15	22	30
Spaghnum peat			1.3	2.7	5.3	10	15	20

STP classes: 1 = poor, 2 = rather poor, 3 = fair, 4 = satisfactory, 5 = good, 6 = high, 7 = excessive

Due to the positive P balances since the 1950´s, STP values have increased from an average value of 5.4 mg l^{-1} in the period of 1955-1960 up to 12.3 mg l^{-1} in 2006-2010 (Fig. 1). The Finnish Agri-Environmental Programs (FAEP) have included restrictions on P use according to STP values since 1995. As an example for cereals, the current FAEP (2007-2013) allows use at the most 34 kg ha^{-1} of mineral P fertilizers when STP is in the lowest category (poor), and thereafter decreasing P applications as STP values increase until no P is allowed at the highest STP class. However, whether the set values for maximum P applications are well justified or not is a matter of debate. In the recent studies (Valkama et al. 2009, Valkama et al. 2011), all relevant Finnish field experiments since the 1920's were gathered and analyzed by meta-analysis techniques to provide yield response curves for P fertilization. According to yield responses, these studies suggested lower P application levels than is currently recommended. The work of Valkama et al. (2011) further showed that for most of the Finnish farms the maximum FAEP limits would be uneconomical when using purchased fertilizer.

Because of the decreasing use of mineral P fertilizers in the past 20 years, relative importance of manure as a P source for plants or as an origin of P losses to the environment has increased. P content of manure is presently higher (8.8 kg ha^{-1} in year 2011; see section 3.4) than what has been sold as mineral fertilizers (5.6 kg ha^{-1} in year 2011). Content of P in manure has remained at a steady level since the 1990´s (Fig 1.), although the total number of livestock farms has decreased by 63 % since the year 1995 (53 745 farms compared to 19 913 farms in 2011) (Matilda Agricultural Statistics, 15.2.2013: http://www.maataloustilastot.fi/en/farm_structure). Due to the rising number of animals per farms (Fig. 2), production of manure has increased locally to such a level that there is often scarcity of land area for manure spreading when following the nitrate directive or, even more FAEP.

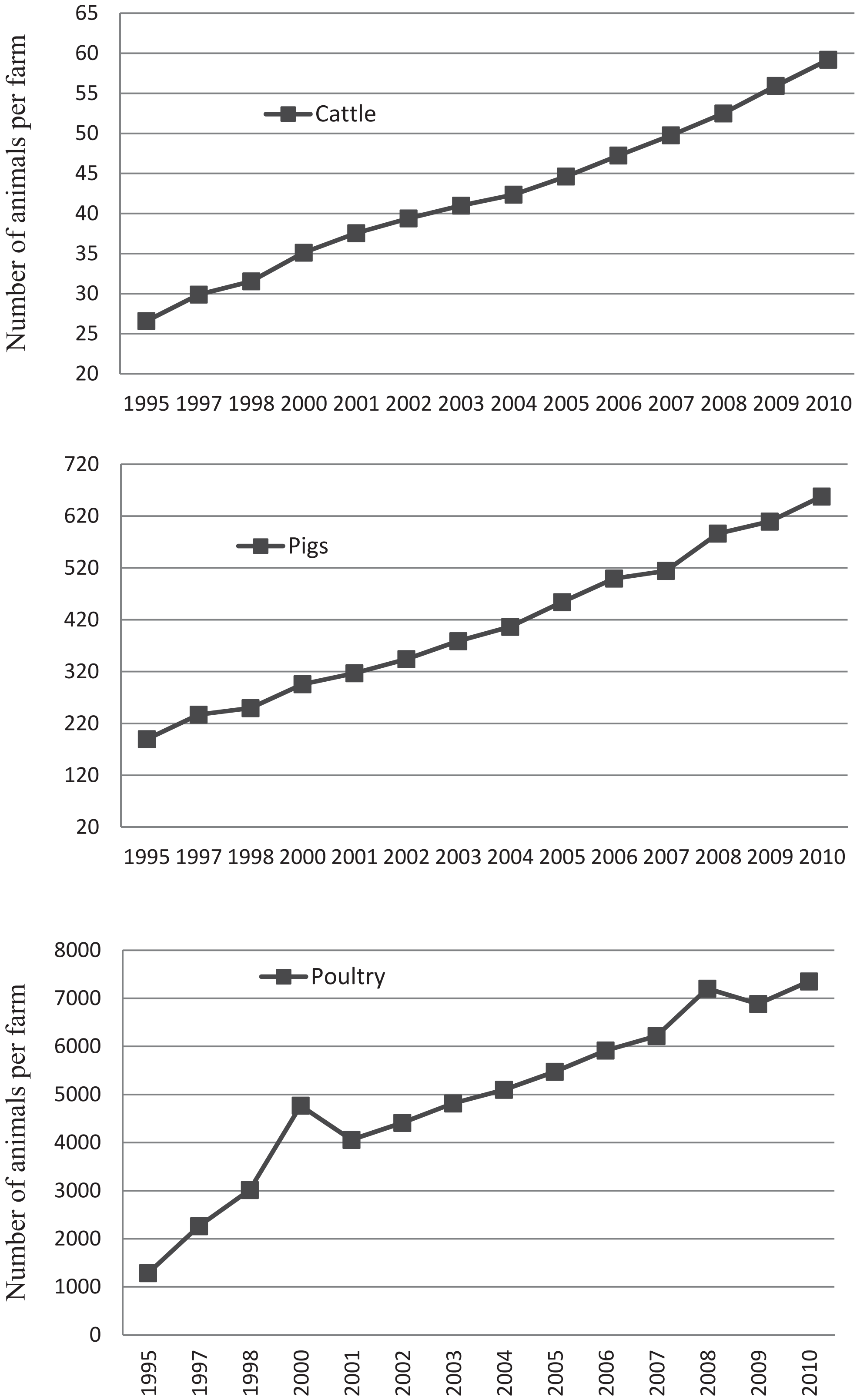


Figure 2. Development of the number of cattle, pigs and poultry per farm during 1995-2010 according to the Information Centre of the Ministry of Agriculture and Forestry (TIKE).

Due to the low nutrient and high water content, manure is commonly spread at the close vicinity of the production houses. As an amendment for livestock farms, the FAEP includes at present an exception for the field parcels that receive only animal manure as P fertilizer. For cereals it is allowed to spread 15 kg P ha^{-1} y^{-1} in manure unless soil P class is "excessive" and for grass 30 kg P ha^{-1} y^{-1} (soil P classes poor to satisfactory) or 20 kg P ha^{-1} y^{-1} (soil P classes good and high). Furthermore, during the previous (2000-2006) and the current FAEP period (2007-2013), 75 and 85 %, respectively, of the total P content in livestock manure (fur animal manures 40 %) was taken into account, thus increasing the allowed application level of P.

In this report we aim to draw a general picture of P stocks in soil, manure and mineral fertilizers as compared to the crop need in different areas of Finland. We present the latest information of the STP status of Finnish agricultural fields and adequacy of soil P and manure P in plant production at a municipality level. Requirement for P fertilization is evaluated according to Valkama et al. (2011). The risk for P loading to recipient waters is estimated with a P-index (Uusitalo et al. 2001).

2. Materials and methods

2.1. Soil data

Since Finland joined the EU (1995), farmers participating in the FAEP have analyzed STP concentration of their fields every fifth year (about 90 % of farms and 92 % of the cultivated field area participating in the FAEP in 2009, Aakkula et al. 2010). In this study the regional summaries of STP values were obtained from the follow-up study of the impacts of FAEP (Aakkula et al. 2010, Uusitalo et al., manuscript) in the period of 2005-2009. The soil data is based on data received from five commercial laboratories covering almost all of the STP analyses. Results included STP, soil texture and organic matter content in the topsoil. However, the data did not include the field size related to the individual samples and thus the STP data represents a distribution of the samples into different STP categories. There is no evidence either that low or high STP values would be concentrated on small or large fields. According to FAEP, soil samples for STP analysis should represent a field size of 5 ha at the most. As total field area is 2.26 million ha, average field size sampled for STP would be 2.24 ha (the final dataset consisted of 1 008 302 soil samples). This equals to the average field size of 2.33 ha in 2012 (Information Centre of the Ministry of Agriculture and Forestry, TIKE, personal communication).

The STP data was checked and filtered with the following criteria: All STP values that rounded to zero or were over 500 mg l^{-1} in the original dataset were excluded as these samples were not considered to represent cultivated soils. Also samples without the information of STP value or soil texture were excluded from the dataset. Samples with incorrect texture or organic matter (e.g. typing mistakes) were removed as well. Due to the quantitation limit of STP analysis in one of the soil laboratories, all their samples that yielded P concentration less than 3.5 mg l^{-1} had been marked as 3.5 mg l^{-1} in their original dataset. Because soil samples for STP analysis represent a field size of 5 ha at the most, number of soil samples of each municipality was compared to their field area. Those municipalities that had less soil samples than is required (field area of each municipality divided by 5 ha) were not included in these data: such municipalities were Kaskinen and Kauniainen and they neither had any livestock animals.

The agricultural area at a municipality level was obtained from TIKE and it included total cultivated area (including cereals, less than 5-year-old grasslands and other crops e.g. potatoes, sugar beets and turnip rapes), fallows (including fallows, nature management fields and green manures), permanent crops (fruit trees, berry plants and nurseries) and kitchen gardens in 2011. Because fallow areas are not fertilized, they were excluded from the calculations of animal densities and manure and fertilizer spreading areas.

2.2. Stock of manure P

Total number of animals, including cattle (dairy cows, suckler cows, heifers over 1 year, bulls over 1 year but under 2 years and bulls over 2 years and calves under 1 year old), pigs (sows, piglets under 20 kg, boars, fattening pigs at least 50 kg, pigs 20-50 kg), poultry (laying hens at least 20 weeks old, chickens under 20 weeks old, broilers, turkeys, cockerels), sheep (with lambs) and goats at a municipality level were provided by TIKE. Total number of fur animals (foxes, minks, finnraccoons and fitchets) was provided by Saga Furs Oyj and Kopenhagen Fur. Number of horses was provided by the Finnish trotting and breeding association (Suomen Hippos ry) and TIKE. Data from TIKE included only horses at farms (31 616 pcs), whereas data from the Finnish trotting and breeding association included all horses in Finland (81 025 pcs). Because the data from the Finnish trotting and breeding association overestimates ca. 10 % the total number of horses (The Finnish trotting and breeding association, personal communication) and location of horses is dictated by their owner’s location, the following correction was done: from the total amount of horses in Finland 10 % was first subtracted and from this value the amount of horses at farms (TIKE's data) was further subtracted and the remainder was divided between municipalities according to proportional share of horses in the municipalities according to TIKE's data.

The numbers of animals were converted to livestock units (LSU) using the livestock unit coefficients (Commission regulation (EC) No 1200/2009). These coefficients are based on the nutritional or feed requirement of different animals and the reference unit is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually without additional concentrated foodstuffs (see Appendix 1). Total amount of manure P produced by each category of animals was based on feeding trials conducted at MTT (Jouni Nousiainen, personal communication) (see Appendix 1).

2.3. Optimum P fertilization rate

Requirement of P fertilizer was calculated for each municipality based on the results of Valkama et al. (2011) by using STP distribution of the analyzed soil samples. This calculation accounts for cereals and grasses and is not necessarily applicable for other crops, e.g. sugar beet or potatoes. According to the above study P fertilization is unlikely to give yield responses for cereals if STP values are higher than 6, 10 and 15 mg l^{-1} in clay, coarse textured mineral and organic soils, respectively. These values represent the P class 3/4 (fair/satisfactory) for mineral soils and 5/6 (good/high) for organic soils according to Finnish soil P classification system (Table 1). Therefore if STP values were higher than the above mentioned values, P fertilization was omitted in the calculations, whereas, as an example, if STP value was 1 mg l^{-1}, the required P fertilization was 59, 24 and 22 kg ha^{-1} in clay, coarse textured mineral and organic soils, respectively, in order to receive 95 % of the maximum yield.

2.4. Phosphorus index

The risk for P transfer from agricultural soil to surface water was estimated by using a simple P-index calculation, based on P site index (Lemunyon and Gilbert 1993), that has been applied for Finnish conditions (Uusitalo et al. 2001). In this method P-index is obtained by dividing soil properties and cultivation practices into six classes (Table 2). Each parameter is given a weight-coefficient and furthermore each parameter is divided into class-coefficients, values ranging from 1-90 (Table 2). For obtaining the final index, each weight-coefficient is multiplied with the class-coefficient and the resulting six values are summed up. Values below 20 indicate relatively low P loading, 20-40 average, 40-60 high and values above 60 extremely high P loading. Parameters describe both the erosion risk (soil texture, slope and plant) and the dissolved P (DRP) loading (P fertilization, method of fertilization and STP class).

For each municipality, share (%) of different soil texture, slope, soil P class and plant categories were multiplied with class-coefficients and sum of these values were multiplied with the corresponding weight-coefficient. Plant information was obtained from years 2005-2009 (MYTVAS 3, Aakkula et al. unpubl.) representing the same period as soil P data. Here, the plant information represents merely tillage intensity and thus the risk of erosion as perennial plants depress erosion and particulate P losses compared to annual crops. Plant data was divided into three categories: average share of annual crops, perennial crops and bare fallow. The bare fallow represented only 0.14 % of total field area during years 2005-2009. However, perennial crops are more commonly fertilized as top-dressing, causing higher DRP loading compared to annual crops where placement fertilization is commonly used (Turtola and Jaakkola 1995, Turtola and Kemppainen 1998). Because of this, P fertilization method was evaluated by using crop information: annual (placement), perennial (top dressing) and e.g. fallows, reforested fields and buffer strips (no fertilization). In this study only manure P was taken into account as P fertilization to elaborate its sufficiency. STP classes were those presented in Table 1 and field slope data was obtained from TIKE.

2.5. Map resolution

Since we were able to retrieve all data (except the sale of mineral fertilizers) at a municipality level, the results are presented on that level to show the variation within Finland. Maps were drawn with the ArcMap 10 program. Åland was considered as one region due to its small proportion of cultivated area, 13 806 ha (0.6 % out of the total field area in Finland). Borders of the Centre for Economic Development, Transport and the Environment (ELY Centres) are presented in the maps as well.

Table 2. Parameter values for calculating the P-index (Uusitalo et al. 2001). The P-index is calculated by multiplying the weight-coefficient of the first column parameters with the appropriate class-coefficient given on the right and finally adding up all six values.

Parameters and their weight-coefficients	Class-coefficients								
	1	3	5	15	20	25	30	45	90
Soil texture (0.12)	Moraine		Very fine, fine, medium, coarse and very coarse sand (0.06 – 2 mm)	Silt loam, silt, loam, coarse silt	sandy clay, sandy clay loam, clay loam, silty clay, silty clay loam (clay content 30-60%)	clay (clay content > 60%)			
Slope, % (0.3)		< 2		2-5			5-10		> 10
Plant (0.6)	perennial		annual						bare fallow
P fertilization, kg ha^{-1} (0.2)	0		< 15	15-30		30-45		> 45	
Method of fertilization (0.3)	no fertilization		placement	top dressing					
Soil P class (0.94)	poor, rather poor		fair		satisfactory			good	high, excessive

3. Results and discussion

3.1. Phosphorus status of cultivated soils

In Finland, the cultivated fields cover 2.26 million ha, totaling 7.4 % of the land area. Western and southern part of Finland have the highest share of cultivated area (Fig. 3, Table 3); with the largest proportion of 51 % in the municipality of Koski Tl. Northern Finland (Lapland) has only 1.9 % of the total cultivated area in Finland. The four ELY Centres that are confined to the coastal area of the Baltic Sea (Southwest Finland, Satakunta and Uusimaa) and Gulf of Bothnia (Ostrobothnia) contain 35 % of the total cultivated field area in Finland (Table 3).

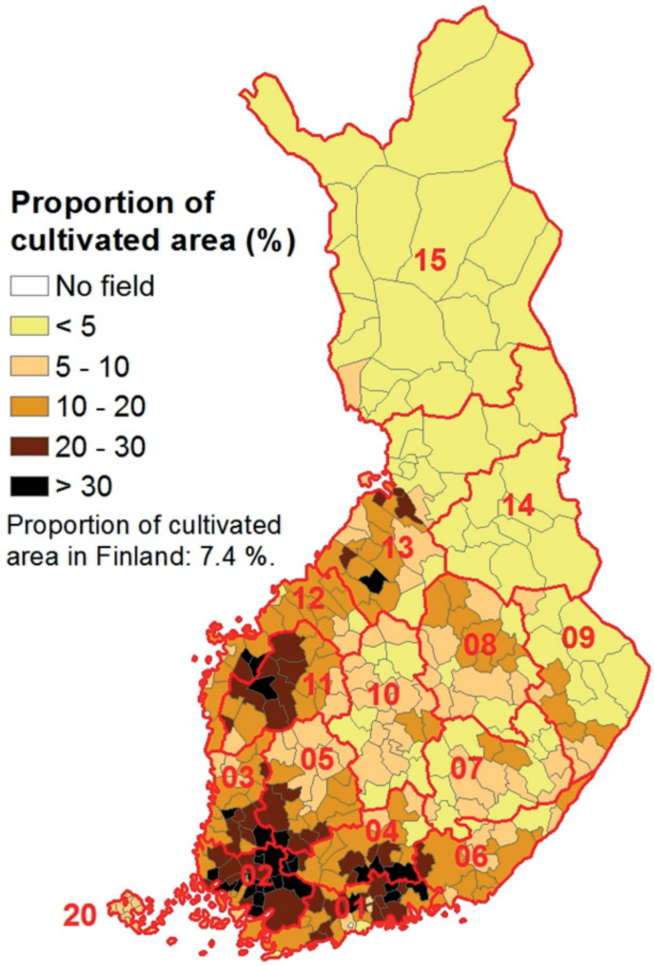
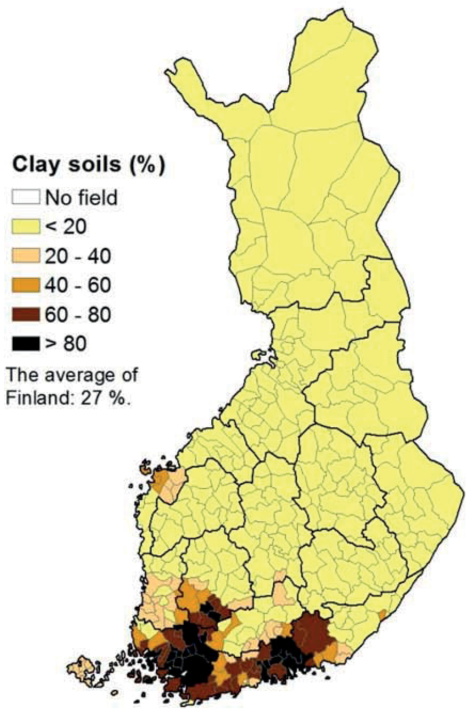
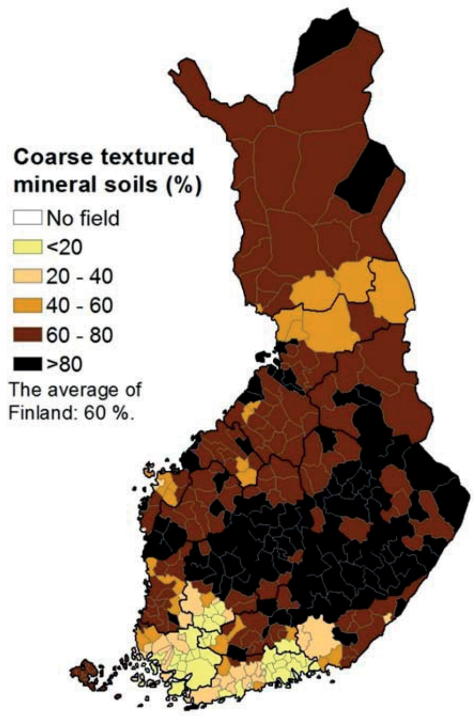


Figure 3. Proportion of cultivated field area out of total land area at different municipalities in Finland. Numbers in the map indicate ELY Centers presented in Tables 3-5.

Depending on soil texture (clay, coarse textured mineral and organic soil), P fertilizer response at a given STP value differs due to the different P buffering capacities of the soil types. Because of this, critical STP values vary between different soil textures. In Finland the dominant soil texture classes are coarse textured mineral soils (Fig. 4), but there are considerable regional differences depending on geology and the past phases of pedogenesis. In the southern part of Finland clay (sedimentary deposits) is the dominant soil texture, whereas in the eastern and northern part of Finland coarse textured mineral soils (unsorted moraine and sorted coarser-textured soils) dominate. This is the outcome of Southern Finland being (ca. 10 000 years ago) longer under water than eastern part of Finland. On the west coast of Finland organic soils dominate because of the slow uplifting of the ground. This region is low-lying and plane with rivers. The river basins are often clayey, but between river basins there is often moraine. In North Finland organic and coarse textured mineral soil types dominate.





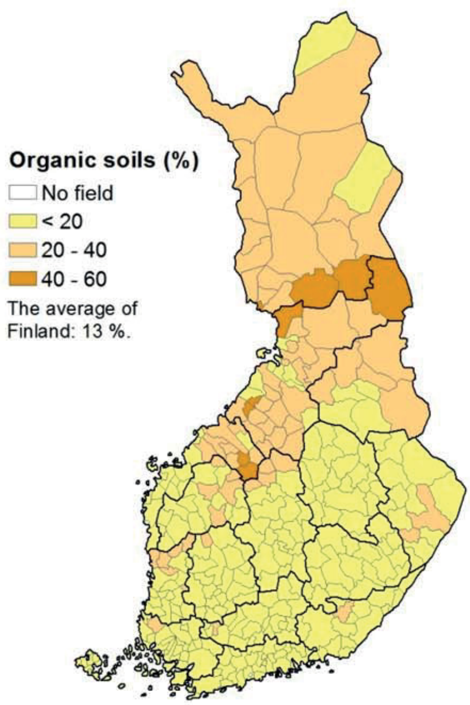


Figure 4. Proportion of clay soils, coarse textured mineral soils and organic soils in Finland.

Table 3. Average field (including fallows) and total land areas and proportion of soil textural classes and soil test P (STP) values (analyzed in 2005-2009) at the level of ELY Centres.

Centre for Economic Development, Transport and the Environment (ELY Centres)	Field area (ha)	Total land area (km^2)	Field area (%)	Soil textures			STP (mg l^{-1})			
				Clay soils (%)	Coarse textured mineral soils (%)	Organic soils (%)	All soil types	Clay soils	Coarse textured mineral soils	Organic soils
Central Finland (10)	97988	16704	5.9	3.9	83.6	12.6	10.0	8.6	10.3	8.4
Häme (04)	187490	10324	18.2	35.9	57.2	6.9	12.2	9.5	14.3	8.1
Kainuu (14)	31687	21501	1.5	1.2	76.2	22.6	11.2	11.5	10.8	12.6
Lapland (15)	43883	92662	0.5	0.7	66.2	33.1	14.1	10.7	14.3	13.6
North Karelia (09)	84843	17763	4.8	5.8	81.8	12.4	9.8	7.7	10.1	8.9
North Ostrobothnia (13)	223714	35507	6.3	2.1	69.5	28.4	13.1	11.5	14.1	10.7
North Savo (08)	147429	16768	8.8	9.3	79.6	11.1	10.4	8.7	10.9	8.3
Ostrobothnia (12)	194198	12769	15.2	12.3	69.4	18.2	16.4	14.1	18.1	11.3
Pirkanmaa (05)	161629	12446	13.0	36.8	56.0	7.2	9.2	8.6	10.0	6.5
Satakunta (03)	143413	7957	18.0	23.5	63.2	13.3	17.6	17.3	19.5	9.1
South Ostrobothnia (11)	246850	13444	18.4	5.4	75.8	18.8	12.6	12.4	13.5	9.1
South Savo (07)	72790	13977	5.2	0.4	87.8	11.8	11.9	11.6	12.2	9.7
Southeast Finland (06)	139621	10761	13.0	35.2	55.7	9.1	11.2	9.0	13.0	8.5
Southwest Finland (02)	290532	10661	27.3	76.6	20.2	3.1	17.2	15.9	23.3	10.5
Uusimaa (01)	181246	9096	19.9	72.7	23.4	3.8	11.2	10.3	14.4	7.5
Åland (20)	13806	1552	8.9	28.4	67.6	4.0	25.3	17.5	29.2	13.9
Whole country	2261116	303893	7.4	27.1	60.0	12.9	13.0	12.3	13.9	9.8

The average STP value for all soil samples during 2005-2009 was 13.0 mg l^{-1} (Fig. 5) and the median was 9.0 mg l^{-1}. Highest STP values were found along the Baltic Sea coast in western Finland, Ostrobothnia region, and in South-West Finland. Also some municipalities in northern Finland (e.g. Enontekiö) have high average STP values, but there the cultivated area out of total land area is very low (on average 0.47 %) compared to an average value of 14 % in the coastal area of Finland. Among the municipalities, the lowest average STP concentration (6.7 mg l^{-1}) was found in Pornainen with low animal density, whereas highest (39.3 mg l^{-1}) in Köyliö with high poultry production combined with the highest proportion of special crop production in Finland (45 % of the field area).

For clay and coarse textured mineral soils, the average STP values were 12.3 and 13.9 mg l^{-1} (Fig. 6). The highest values are found in municipalities with a high animal density. Organic soils had a lower average STP concentration, 9.8 mg l^{-1}, than mineral soils (Fig 6).

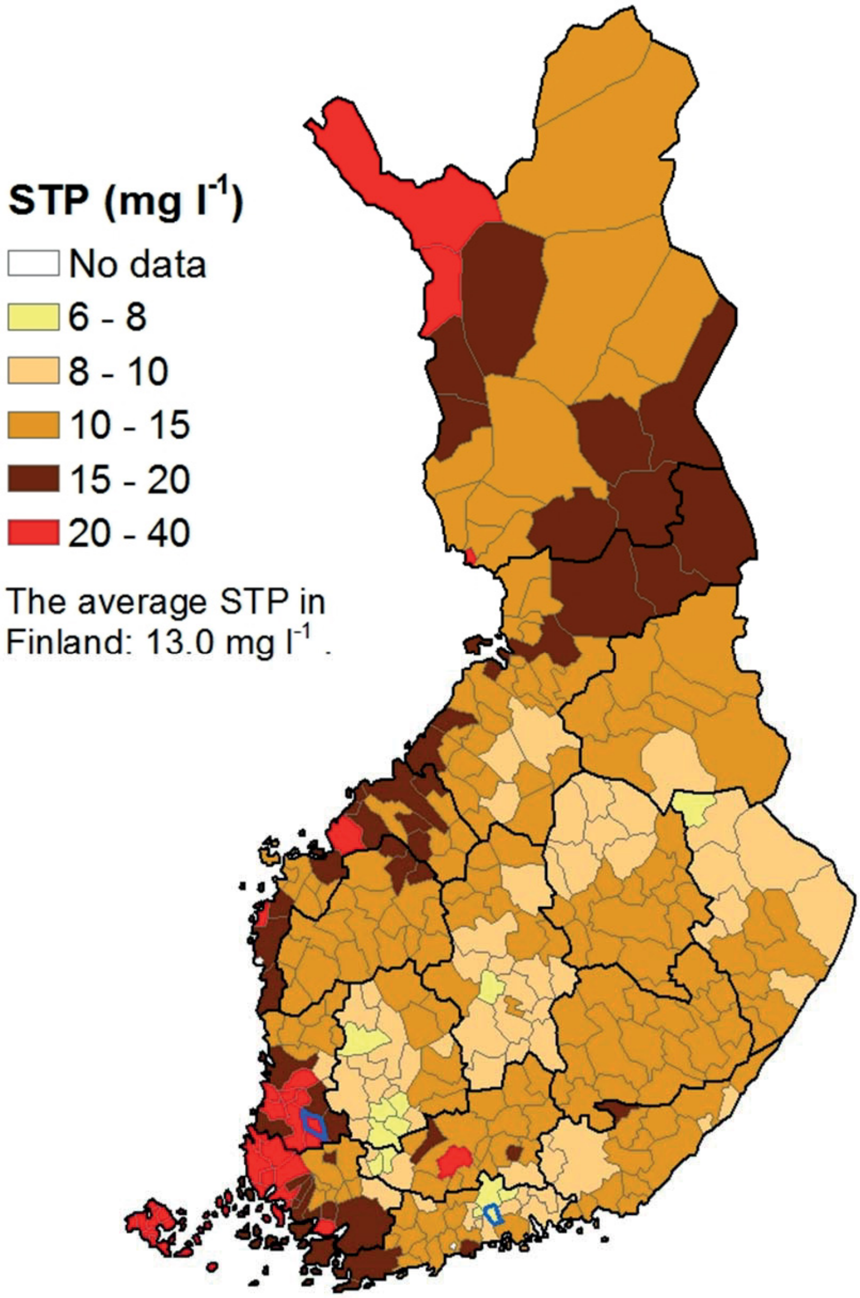
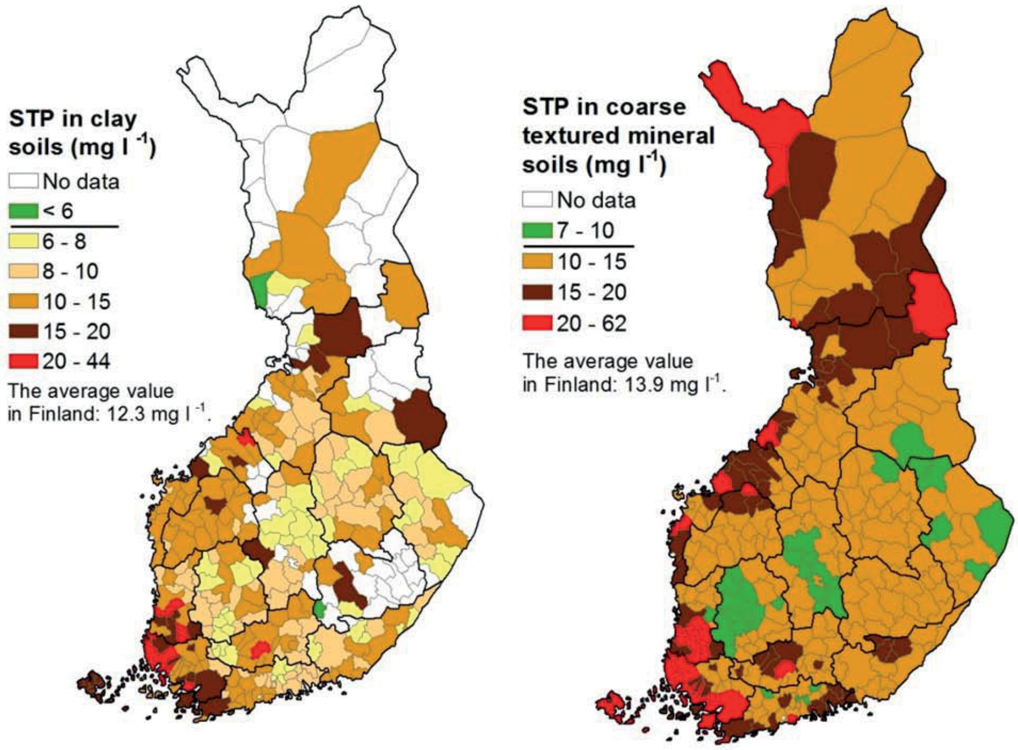


Figure 5. Average soil test phosphorus (STP) values in Finland. Köyliö (with the highest average: 39.3 mg l^{-1}) and Pornainen (with the lowest average: 6.7 mg l^{-1}) are circled as blue.



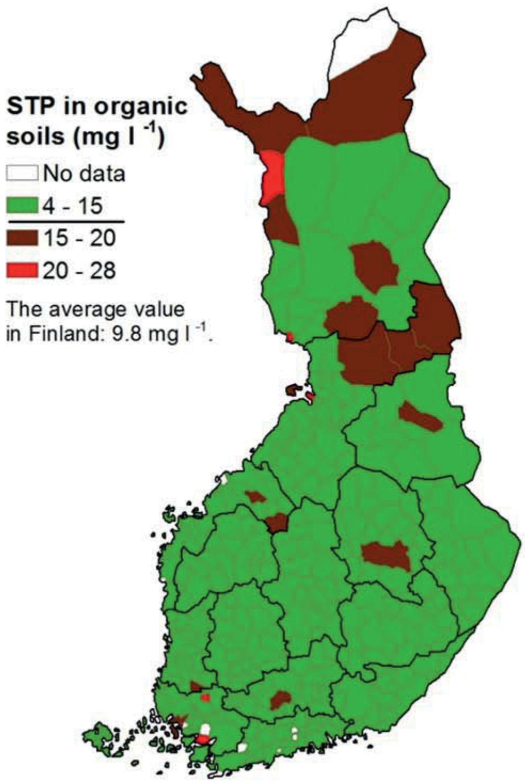


Figure 6. Average STP values at a municipality level in clay, coarse textured mineral and organic soils in Finland. Green color indicates response to P fertilization. Municipalities with less than ten samples are not included.

3.2. Requirement for P fertilization

On the average, 8.6 kg P ha^{-1} is required for cultivated fields in order to achieve 95 % of the maximum yield in Finland (Fig. 7). Due to the past P fertilization history, ca. 49 % of the analyzed soil samples had such STP values that P fertilization is unlikely to produce any yield response (Fig 8). However, this calculation accounts for cereals and grasses and is not necessarily applicable for other crops, e.g. sugar beet or potatoes. Nevertheless, cereals and grasses covered 90 % of the cultivated field area of Finland in 2011 (Matilda Agricultural Statistics, Utilised Agricultural Area 2012 by region, 26.8.2013; http://www.maataloustilastot.fi/en/utilised-agricultural-area-2012_en).

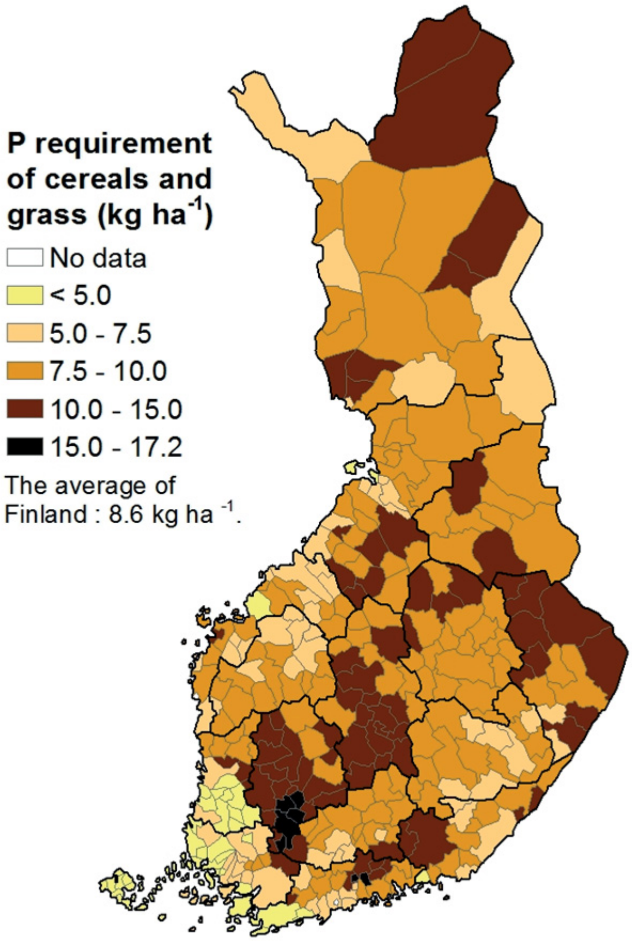


Figure 7. Phosphorus fertilizer requirement of cereals and grasses (grown in all cultivated fields) in Finland as calculated according to STP values in 2005-2009 and results of Valkama et al. (2011).

Due to the dominant share of clay soils (Fig. 4) and high STP values (Fig. 5) in the south-western coastal area of the Baltic Sea, P requirement is lowest in Southwest Finland and Satakunta, about 6 kg ha^{-1} (Table 4). The municipalities with the highest share of non-responsive soils for P fertilization are mainly located in this area. In Southwest Finland and Satakunta, proportion of cereals and grasses was about 85 % of the cultivated field area, demonstrating relatively higher share of other crops, e.g. sugar beet, potatoes, peas, turnip rape and rape.

As an example, while Köyliö had the highest mean STP value (39.3 mg l^{-1}) and only 12 % of the analyzed soil samples represent fields that require P fertilization, the corresponding value for Valtimo was 82 % (mean STP 7.4 mg l^{-1}). In municipalities situated in central Finland and in some regions of eastern Finland more than 60 % of the analyzed soil samples represent fields that are responsive for P fertilization.

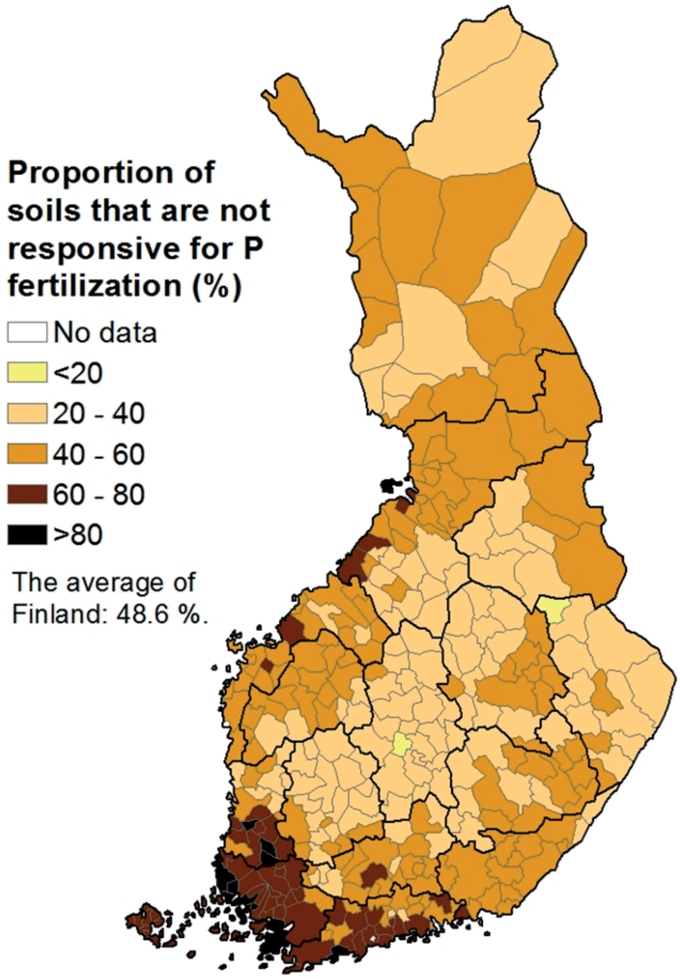


Figure 8. Proportion of soil samples where P fertilization is unlikely to increase yield in Finland.

The likelihood for yield responses is clearly variable between the soils of different textures. Least responsive are clay soils, of which 69 % had such a high STP value that P fertilization is unlikely to provide any yield response, followed by coarse textured mineral (47 %) and organic (14 %) soils (Fig. 9). At a municipality level proportions can be much higher than at the country level. For example there are several municipalities where the proportion of non-responsive clay soils is over 90 % (Vimpeli 97 %, Köyliö 96 %, Säkylä 96 %, Uusikaarlepyy 96 %, Naantali 95 %, Lappajärvi 94 %, Inkoo 93 %, Harjavalta 93 %, Ähtäri 93 %, Uusikaupunki 92 %, Taivassalo 92 %, Pyhäranta 92 %, Kuortane 92 %, Eura 91 %). Similarly, in many municipalities, the proportion of non-responsive coarse textured mineral soils is over 80 % (Köyliö 90 %, Naantali 89 %, Uusikaupunki 84 %, Taivassalo 83 %, Hailuoto 83 %). The highest proportion of non-responsive organic soils is in Hailuoto (63 %). Most of these municipalities are located in the western coastal area and have intensive animal production or large proportion of fields under sugar beet or potatoes.

Table 4. Requirement for P fertilization, proportion of non-responsive soils for P fertilization, and sale of mineral P fertilizer in 2011 (Tapio Salo, personal communication) at level of ELY Centres.

Centre for Economic Development, Transport and the Environment (ELY Centres)	P requirement (kg ha^{-1})	Proportion of soils that are not responsive for P fertilization (%)				Sale of mineral P fertilizer (kg ha^{-1})
		All soil types	Clay soils	Coarse textured mineral soils	Organic soils	
Central Finland (10)	10.2	31.9	56.1	34.3	8.6	4.3
Häme (04)	9.6	47.8	56.6	47.0	9.0	6.9
Kainuu (14)	9.7	34.9	68.1	36.2	29.0	4.7
Lapland (15)	9.2	39.6	57.8	44.8	28.5	3.5
North Karelia (09)	10.5	32.0	53.3	33.5	12.2	4.5
North Ostrobothnia (13)	8.5	43.3	71.5	52.8	17.9	6.0
North Savo (08)	9.3	38.1	63.3	39.3	8.1	5.0
Ostrobothnia (12)	7.3	52.4	78.5	57.0	17.5	5.5
Pirkanmaa (05)	12.3	35.7	51.1	29.6	4.1	4.5
Satakunta (03)	6.2	59.9	82.3	62.0	9.9	6.4
South Ostrobothnia (11)	8.0	44.7	81.0	50.6	10.4	6.0
South Savo (07)	8.1	40.4	58.6	44.1	13.0	5.5
Southeast Finland (06)	9.2	47.7	60.4	46.2	8.2	6.0
Southwest Finland (02)	6.3	72.6	77.1	64.9	13.0	5.7
Uusimaa (01)	8.6	60.9	67.5	49.5	5.2	6.3
Åland (20)	4.4	76.0	79.9	77.0	29.6	-
Whole country	8.6	48.6	68.7	47.0	13.8	5.6

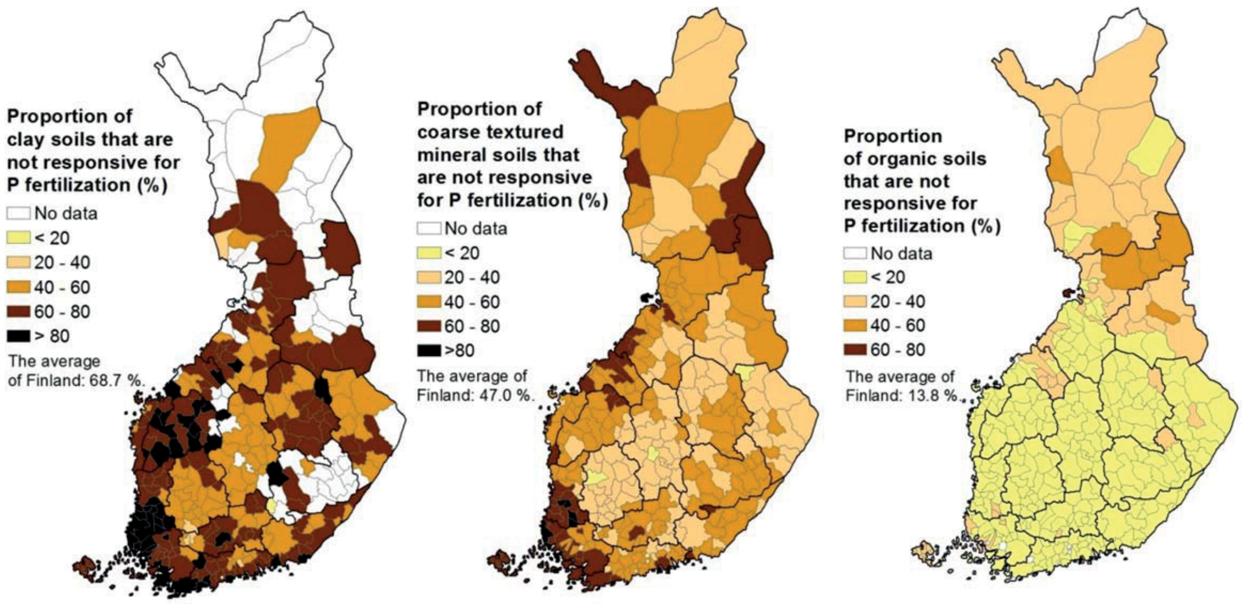


Figure 9. Proportion of soil samples in clay, coarse textured mineral and organic soil groups that are unlikely to produce any yield response after P fertilization.

The idea behind earlier P fertilization recommendations was to bring the STP class to "satisfactory". The corresponding STP values for clay soils range from 6-15 mg l^{-1} and for coarse textured mineral and organic soils from 8-22 and 5.3-15 mg l^{-1}, respectively (Table 1). When considering that STP values above which there is no yield response are 6, 10 and 15 mg l^{-1} for clay, coarse textured mineral and organic soils, respectively (Valkama et al. 2011), the target values for STP for clay and coarse textured mineral soils have been higher than it was recently shown to be adequate for the optimum yield. For organic soils, however, "satisfactory" value for STP is at range where P fertilization is likely to provide yield increase. The difference between the interpretation of STP values and plant responses to P fertilization between mineral and organic soils has its origin in the lower buffering capacity of P and concomitant greater P leaching potential in organic soils compared to the mineral ones (Cogger and Duxbury 1984, Fox and Kamprath 1971).

3.3. Distribution of production animals

Total number of cattle, pigs and poultry was about 0.9, 1.3 and 9.8 million, respectively, in Finland in year 2011. Cattle are more evenly distributed throughout Finland than pigs and poultry (Fig. 10). Most of the cattle are located in the Ostrobothnia and eastern Finland though (65 %), whereas pigs and poultry are mainly located in the South-West and western part of Finland and fur animal production in the Ostrobothnia region (Fig. 10). Total number of other production animals (about 0.2 million, 1.3 % of total number of animals), e.g. sheep, goat and horses are of lower significance (Fig. 10), when considering the production of manure P (5.3 % of the total stock of manure P). Most of these animals are located in the southern Finland.

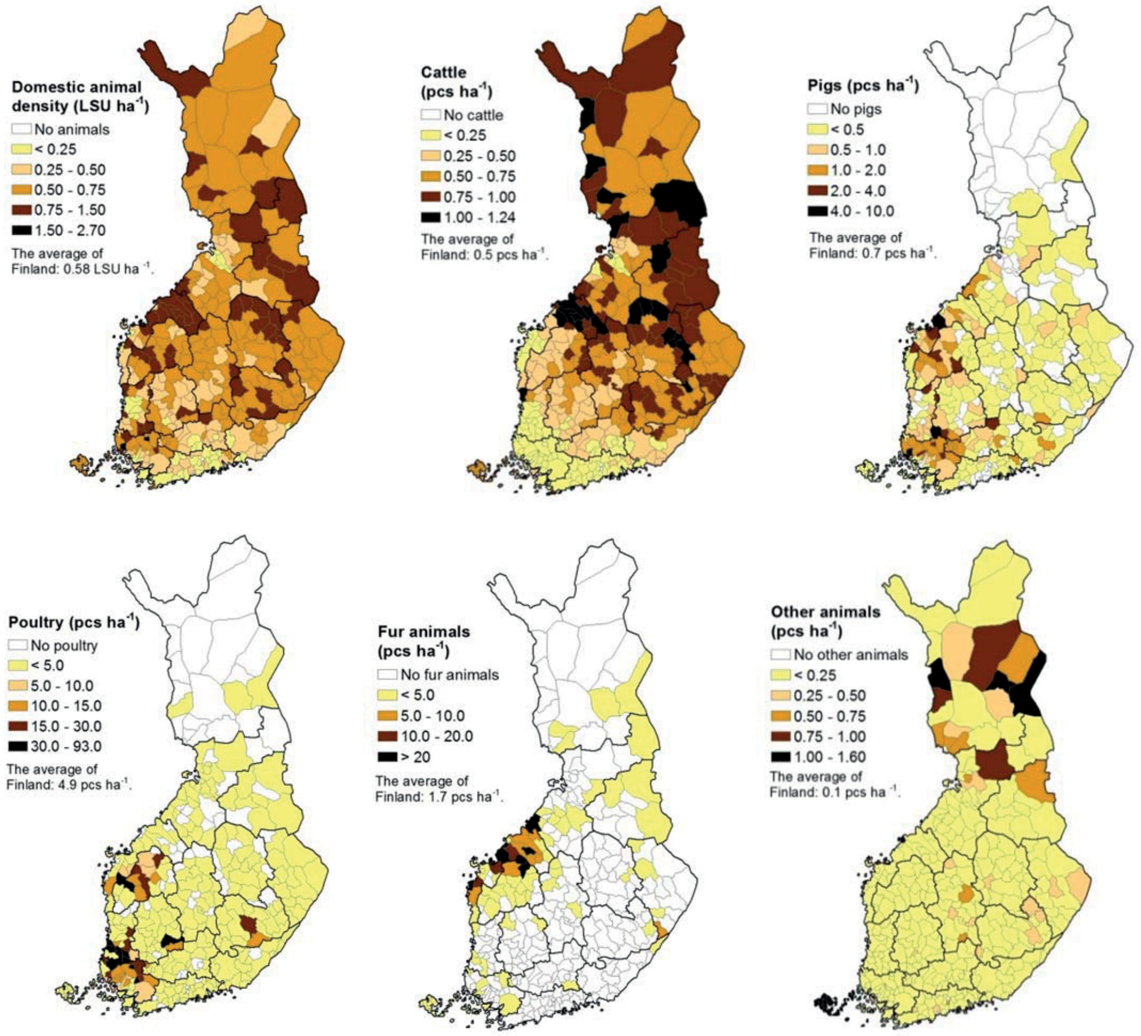


Figure 10. Domestic animal density (LSU = livestock unit) and density of cattle, pigs, poultry, fur animals and other animals (goats, sheep and horses) in Finland (number of animals per ha).

3.4. Stock of manure P

Content of P in animal manure in Finland was about 17.5 million kg in year 2011 (Table 5). Most of this originated from cattle (9.8 million kg), followed by pigs (3.6 million kg), fur animals (1.8 million kg) and poultry (1.5 million kg). Large part of the manure P, about 42 %, was produced in the Ostrobothnia region, where at one municipality (Pietarsaari) the production of manure P was as high as 202 kg ha^{-1} (Fig. 11). However, there the field area (fallow excluded) was only 427 ha. While the maps indicate relatively high input of manure P per hectare in northern Finland, it must be noted that there the total field area is small.

Most of the fur animal farms are located in the Ostrobothnia region, where about 97 % of the fur pelts are produced. Due to the high P concentration in fur animal diets, P content of manure is also at a high level. When fur animal manure is spread according to FAEP (years 2007-2013), only 40 % of the total P is taken into account, which leads to P accumulation in soils. Although P in fur animal manure is originally less soluble than in dairy manure or in superphosphate, it turns into a plant-available form in slightly acidic soils (Ylivainio et al. 2008, Ylivainio and Turtola 2009). It was also shown that P leaching into deeper soil profiles occurs when fur animal manures are repeatedly and excessively applied (Uusitalo et al. 2007).

Pig and poultry are the main livestock animals in south-western Finland (Fig. 10), thus producing most of the manure P in these areas (Fig. 12, Table 5). In the eastern Finland, however, where cattle dominates, manure P is produced quantitatively (kg ha^{-1}) more than in South-West Finland (Fig. 11). However, STP values are at a higher level in south-western Finland due to a different P fertilization history and a high use of mineral P fertilizers associated with crops such as sugar beet, potato and vegetables (Fig. 13). Recommendations for P fertilization are also at a higher level for special crops compared to cereals and grass, thus still increasing the soil P stock.

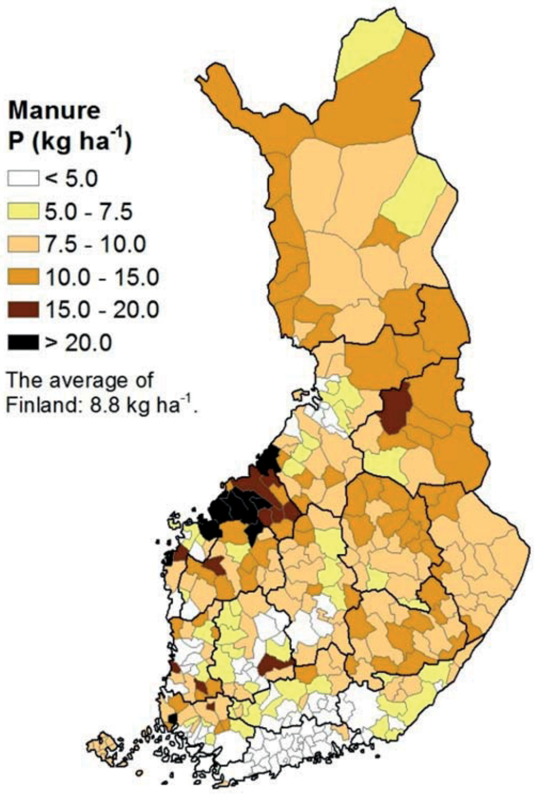


Figure 11. Manure P production in Finland.

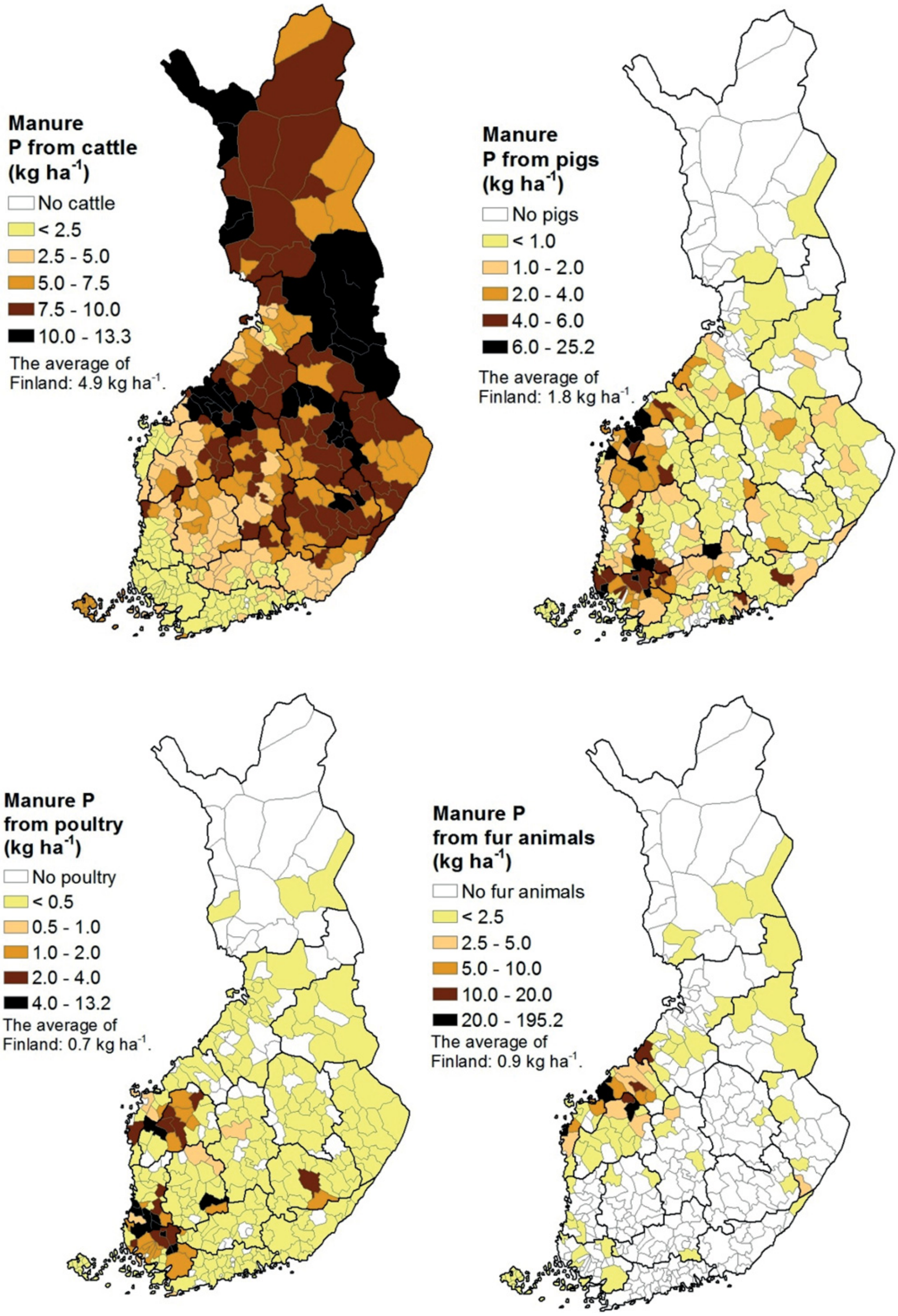


Figure 12. Manure P produced per hectare by cattle, pigs, poultry and fur animals in Finland.

Table 5. Domestic animal density, production of manure P and sufficiency of manure P when fertilized according to plant need at the level of ELY Centres in 2011.

Centre for Economic Development, Transport and the Environment (ELY Centres)	Domestic animal density (LSU ha^{-1})	Manure P (kg y^{-1})	Manure P (kg $ha^{-1}y^{-1}$)						Manure P surplus or deficiency when fertilized according to plant need (kg ha^{-1})
			All animals	Cattle	Pigs	Poultry	Fur animals	Other animals	
Central Finland (10)	0.6	660825	8.1	6.6	0.5	0.1	0.1	0.8	-2.2
Häme (04)	0.4	845230	5.2	3.1	1.5	0.1	0.0	0.4	-4.4
Kainuu (14)	0.6	281818	10.1	9.2	0.1	0.1	0.2	0.5	0.4
Lapland (15)	0.7	416974	10.1	9.0	0.0	0.0	0.1	1.0	0.9
North Karelia (09)	0.6	692242	9.3	8.2	0.3	0.1	0.2	0.5	-1.1
North Ostrobothnia (13)	0.6	1834620	9.2	7.2	0.7	0.0	0.9	0.3	0.7
North Savo (08)	0.7	1426763	10.6	9.5	0.6	0.0	0.0	0.4	1.4
Ostrobothnia (12)	0.8	3075204	17.3	6.2	3.5	0.5	6.9	0.3	10.0
Pirkanmaa (05)	0.5	982555	7.1	4.0	1.7	0.9	0.0	0.5	-5.2
Satakunta (03)	0.6	1063254	8.2	2.5	2.9	2.4	0.0	0.3	2.1
South Ostrobothnia (11)	0.7	2517664	11.5	5.2	2.8	1.5	1.6	0.3	3.5
South Savo (07)	0.7	612563	9.8	8.0	0.6	0.4	0.0	0.8	1.7
Southeast Finland (06)	0.4	611780	5.4	3.9	0.8	0.1	0.0	0.6	-3.8
Southwest Finland (02)	0.6	1931876	7.4	1.4	3.7	2.0	0.0	0.3	1.1
Uusimaa (01)	0.2	455258	3.0	1.7	0.6	0.0	0.0	0.7	-5.6
Åland (20)	0.6	107248	8.4	6.1	0.0	0.2	0.2	1.9	4.0
Whole country	0.6	17515875	8.8	4.9	1.8	0.7	0.9	0.5	0.3

3.5. Use of mineral P fertilizer

For the use of mineral P fertilizer, it was not possible to get the data for different municipalities. Therefore the data is not as detailed as for manure P and soil test P but rather the differences between areas are leveled off. In South-West Finland (ELY Centres of Satakunta and Southwest Finland), the sales of mineral P fertilizer were on average 5.7-6.4 kg ha^{-1} in 2011 (Table 4). Only in the region of Häme more P fertilizer was sold (6.9 kg ha^{-1}). This is explained by the special crop cultivation in these areas (Fig. 13). In Satakunta the proportion of special crop cultivation out of the total cultivated area is on average 8.7 % and in Southwest Finland and Häme 5.1 % and 3.0 % respectively. These areas cover 49 % of the total special crop cultivation in Finland. The most common special crops in South-West Finland are sugar beet, horticultural crops and potato (Matilda Agricultural Statistics, 26.8.2013; http://www.maataloustilastot.fi/en/utilised-agricultural-area-2012_en). One reason for the higher sale of inorganic P fertilizer in Ostrobothnia region is potato cultivation.

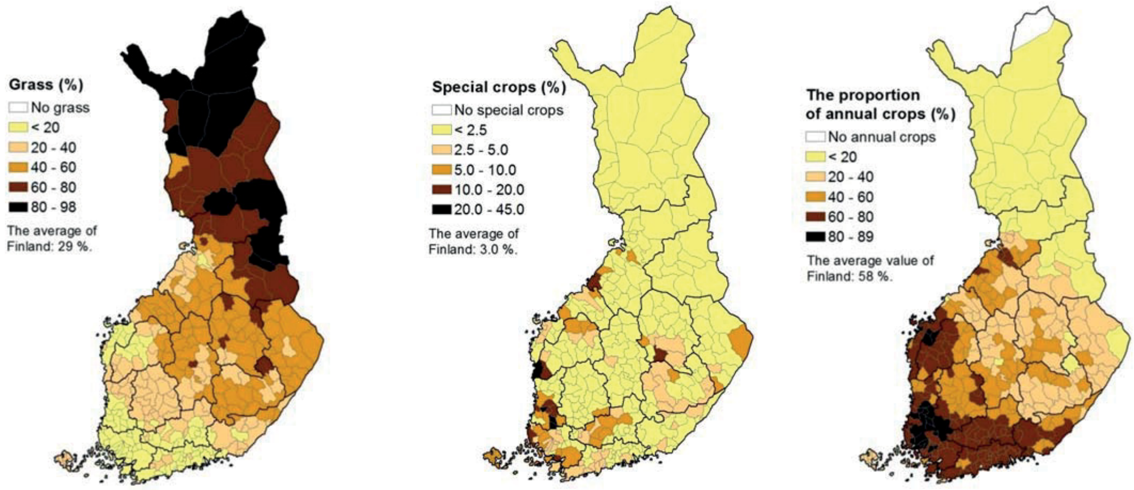


Figure 13. Proportion of grass, annual crops and special crops in Finland in 2005-2009.

3.6. Sufficiency of manure P as the sole source of P for plants

Although the content of P in manures in most of the municipalities is less than what is removed with the crop, manure P would still be enough to sustain yields at the optimum level in 147 out of 336 municipalities (Fig. 14). This is a consequence of the past P fertilization history that has increased STP values to a high level. Average STP values for clay and coarse textured mineral soils for example (Fig. 6) are above the level where P fertilization is unlikely to provide yield increase. Highest surplus of manure P is produced in the Ostrobothnia region (Table 5). There the highest surplus of manure P is found in Pietarsaari (194 kg ha^{-1}) due to the fur animal production with a small field area. However, in Järvenpää (Uusimaa), with a low animal density, the deficit is 15.4 kg ha^{-1}.

Municipalities with the highest P surplus have intensive fur, pig, poultry or cattle production. In these municipalities there is a potential to export manure to other regions with lower animal density or areas which are focused on crop production, mainly cereals and other annual crops. The cereal farms often provide fodders for livestock farms and replace nutrients exported as fodder with inorganic fertilizers. Recycling of manure back to cereal farms would be needed to prevent further accumulation of nutrients to areas with intensive livestock production.

If manure P could be spread according to plant requirement throughout Finland, there would be slight P surplus (0.3 kg ha^{-1}; Fig. 14) and the use of mineral P fertilizer could be totally omitted. However, even at the municipality level manure P is not evenly distributed throughout the cultivated fields, but rather there exists large variation in P surpluses between different farms.

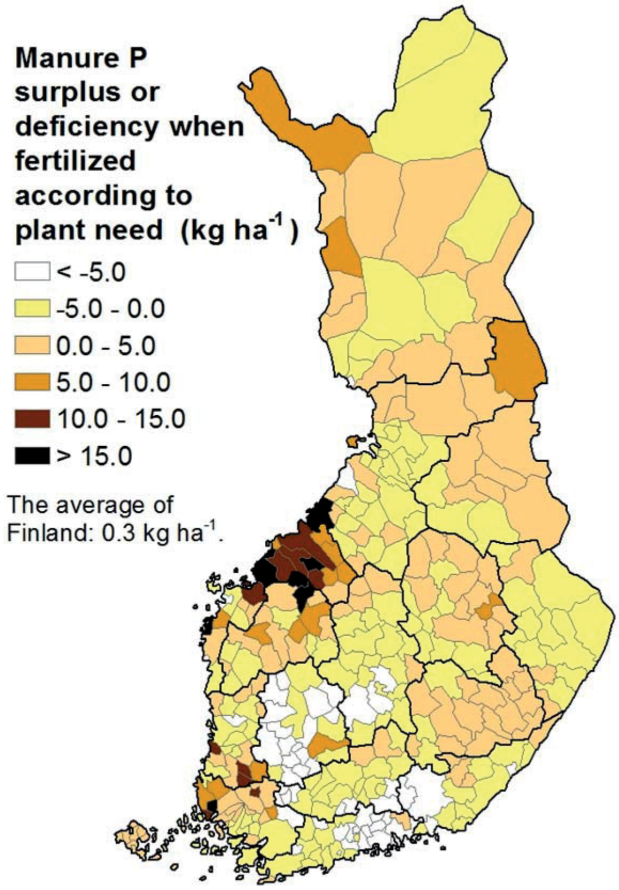


Figure 14. Surplus or deficit of manure P if used as sole P fertilizer in Finland.

Concentrations of easily soluble P in the fields adjacent to river basins of the coastal areas are critical when considering P leaching into the Baltic Sea. Decreasing STP values would be an efficient way to depress P leaching (Uusitalo and Aura 2005). Current STP values in Southwest Finland and Satakunta (ELY Centres) and manure produced in these areas could sustain P requirement by the plants at the moment if only cereals and grasses are cultivated (Table 5). At the same time the use of mineral fertilizer could be omitted. Furthermore, some of the manure produced in these areas should be transported to areas with actual need of P.

3.7. Risk of P loading

Soil texture, field slope and plant type affect the estimated risk for soil erosion when calculating P-index. Clay soils are the most common soil textural class in South-West Finland (Fig. 4) and typically associated with annual crop cultivation (Fig. 13) that increases risk of soil erosion and, therefore, risk for particulate P loading. These clay soils are usually tilled in autumn thus increasing soil erosion during autumn rainfalls and snowmelt in spring. In eastern Finland, coarse textured mineral soils (Fig. 4) and grass (Fig. 13) dominate, which decreases the risk for particulate P loading.

Unlike particulate P loading, potential DRP loading may be at a higher level in areas with a high share of grass (Fig. 13), where fertilization is often done as topdressing, accumulating P at the topmost soil layer and potentially increasing P leaching.

Steeper field slopes and high proportion of clayey soils in the river basins of South-West Finland cause high erosion risk (Tattari et al. 2012), whereas coastal part of western Finland is dominated by low lying fields and most of the fields have slopes less than 2 % (Fig. 15) and soils are mainly coarse textured. This indicates lower erosion risk compared to South-West Finland.

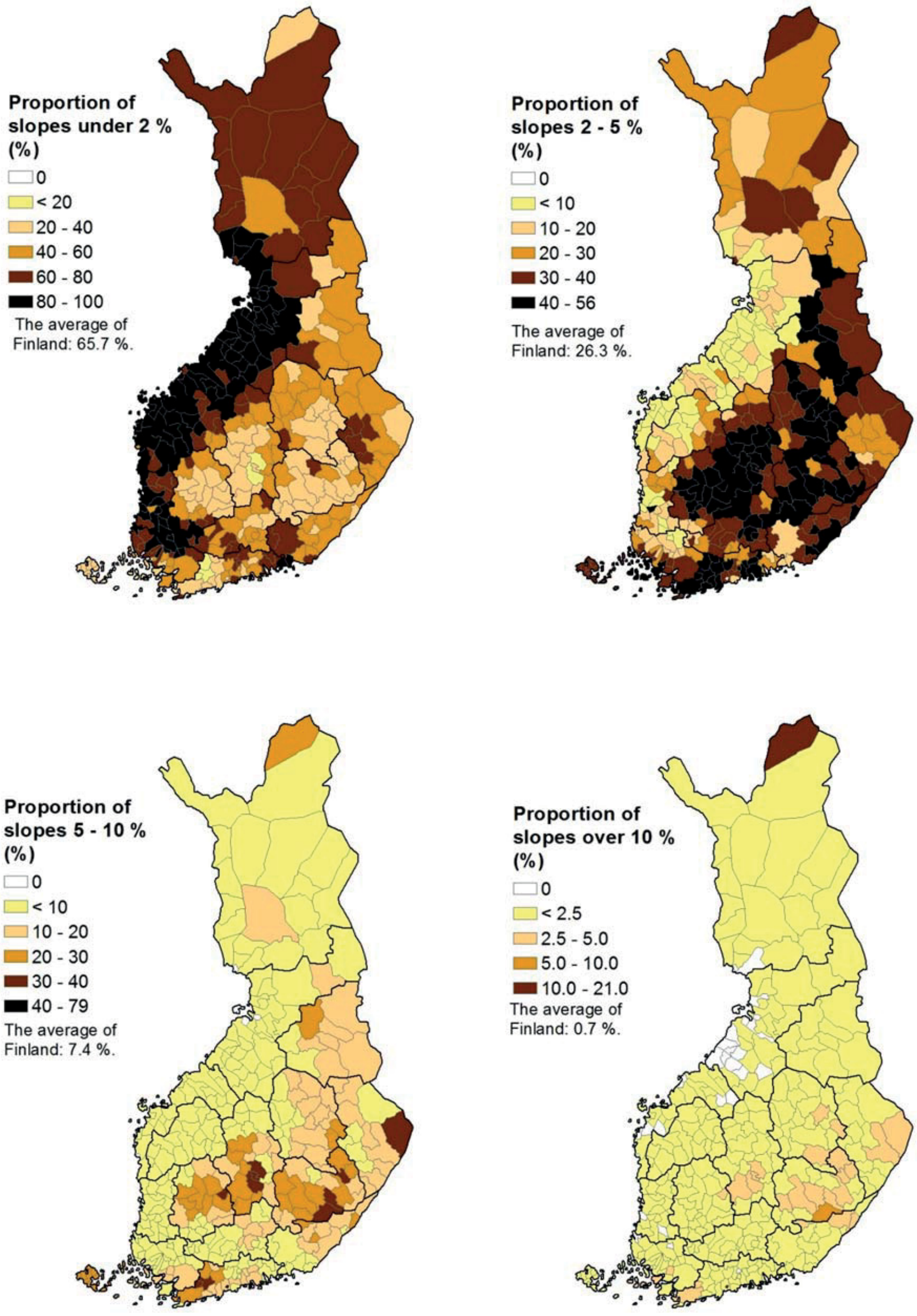


Figure 15. Proportion of field slope categories in Finland.

According to our estimation of P loading index, most Finnish municipalities have an average P loading index (Fig. 16). Most importantly, in coastal areas of western Finland and in South-West Finland and Satakunta, the P-index indicates increased risk for P loading to surface waters. Of the P-index factors, STP class has the heaviest weight. This is in line with the observation that the Finnish STP method (acid ammonium acetate) and water extraction of soil are closely correlated, thus predicting DRP load into recipient waters (Uusitalo and Jansson 2002). Hence, the highest P-index values were estimated for municipalities with the highest STP values.

High P-index values in western Finland are thus mainly caused by the high DRP loading risk due to the high STP values, while in South-West Finland both STP and soil erosion risk are responsible for the elevated loading risk of P.

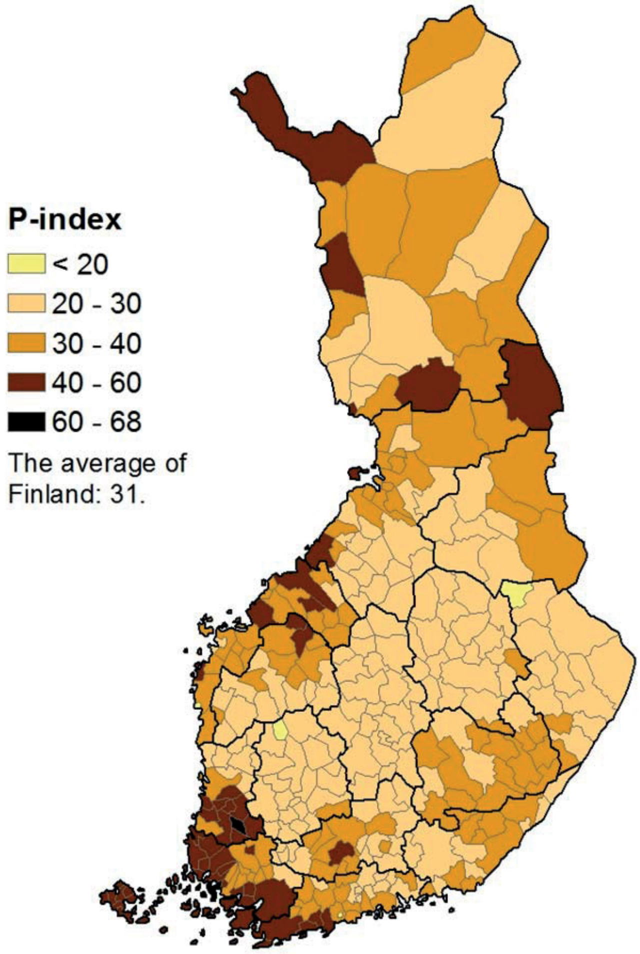


Figure 16. Phosphorus index values in Finland.

4. Conclusions

Presently high STP values are a risk for water systems via P leaching. The highest STP values are found in South-West Finland and Ostrobothnia region, which are situated in the coastal regions of the Archipelago Sea and the Gulf of Bothnia. High STP values are due to intensive livestock production and past P inputs. At present, these regions are an important source of P losses from agriculture to the Baltic Sea, as shown by the P-index values. Of all the analyzed soil samples in Finland, 49 % had such a high STP that P fertilization is unlikely to increase yields. Respective shares for clay, coarse textured mineral soils and organic soils were 69, 47 and 14 %.

Due to the intensive livestock production in South-West Finland (pigs, poultry) and Ostrobothnia (cattle, pigs, fur animals) there are many municipalities that produce more manure than is needed to satisfy plant P need as a sole P source within the particular municipality. While in our calculations manure P was spread across all the cultivated fields within the given municipality, in reality this is unlikely. Instead, the spreading areas are much smaller, increasing the local surpluses in these high-intensive livestock production areas.

At the moment, P content of manure in Finland provides adequate amount of P for plants to reach 95 % of the maximum yield, if only cereals and grasses were cultivated (cereals and grasses covered 90 % of the cultivated field area in 2011) and P was used optimally. This is a result of the high content of easily soluble P in soils due to the excessive P fertilization in the past. In the coastal area of the Baltic Sea, special crops are more common and P fertilizer recommendations for these crops are at a higher level than for cereals and grasses. However, unlike for cereals and grasses, P fertilization recommendations rates for special crops have not been scientifically evaluated and should be therefore cautiously reviewed.

In order to utilize manure P efficiently in crop production manure should be used according to plant need. New innovative manure processing technologies are urgently needed to make transportation easier and economically viable. Moreover, farmers also need knowledge of optimum P fertilization rates for different crops at a given STP level.

If crops were fertilized according to their P need with manure P as a primary P source instead of mineral P fertilizer, inorganic non-renewable P resources could be saved and STP levels would settle more even throughout the country. Moreover, the P load from agriculture to water systems would be reduced. Our results show that there is a marked potential to redistribute manure P without yield losses and with positive effects on the water quality of the Baltic Sea.

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6. Appendices

Appendix 1. Annual P excretion and livestock unit coefficients by animal type.

Animal	Manure P (kg animal^{-1} y^{-1})	Livestock unit coefficient
Dairy cows	19.66	1.0
Suckler cows	12.32	0.8
Heifers over 1 year	6.34	0.7
Bulls 1-2 years	8.24	0.7
Bulls over 2 years	8.24	1.0
Calves under 1 year	5.04	0.4
Sows (with piglets)	7.26	-
Sows	-	0.5
Piglets under 20 kg	-	0.027
Fattening pigs at least 50 kg	3.99	0.3
Boars	5.29	0.3
Pigs 20-50 kg	1.94	0.3
Laying hens at least 20 weeks old	0.15	0.014
Broilers	0.14	0.007
Chickens under 20 weeks old	0.11	0.014
Cockerels	0.23	0.03
Turkeys	0.36	0.03
Sheep with lambs	1.57	0.1
Goats with gilts	1.62	0.1
Horses	9.72	0.8
Minks and fitchets	0.28[1]	-
Foxes and finnraccoons	0.75[1]	-

[1] kg pelt^{-1} y^{-1}

luke.fi

Natural Resources Institute Finland
Viikinkaari 4
FI-00790 HELSINKI, FINLAND
Tel. +358 29 532 6000

luke.fi

Natural Resources Institute
Finland
Viikinkaari 4
FI-00790 Helsinki, Finland
tel. +358 29 532 6000

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