Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Institutionen för mark och miljö

NLeCCS - a system for calculating nutrient leakage from arable land

Holger Johnsson, Kristina Mårtensson, Anders Lindsjö, Kristian Persson och Karin Blombäck

Ekohydrologi 177 Uppsala 2022

Titel:	NLeCCS - a system for calculating nutrient leakage from arable land
Författare:	Holger Johnsson, Kristina Mårtensson, Anders Lindsjö, Kristian Persson och Karin Blombäck
Kontakt:	Holger.Johnsson@slu.se, 018 – 67 24 55
Utgivningsort:	Uppsala
Utgivningsår:	2022
Omslagsbild:	Foto: Anders Lindsjö
Serietitel:	Ekohydrologi
Delnummer i serien:	177
ISSN:	0347-9307
ISRN:	SLU-VV-EKOHYD-177-SE
Elektronisk publicering:	http://pub.epsilon.slu.se
Bibliografisk referens:	Johnsson, H., Mårtensson, K., Lindsjö, A., Persson, K. och Blombäck, K. (2022). *NLeCCS - a system for calculating nutrient leakage from arable land*. Uppsala: Sveriges lantbruksuniversitet. (Ekohydrologi, 177).

Content

Introduction

Calculation of leakage from arable land

Leakage of nitrogen and phosphorus from arable land into surface- and groundwater need to be quantified in order to estimate the impact on lakes, oceans, and groundwater. Leakage of these nutrients is a natural process that takes place from all land but in very varying degrees dependent on e.g. climate and soil type. It is also affected by different cultivation measures, e.g. fertilization and crop type, and varies greatly from year to year, primarily due to varying weather conditions. Leakage losses from soils give rise to so-called diffuse emission (as opposed to point source emissions such as sewage treatment plants) that are very difficult to measure and monitor. It consists partly of leaching through the soil profile and partly by transport via surface runoff.

Nitrogen and phosphorus leakage can be defined as the nitrogen and phosphorus transported down through the soil (leaching) passing the root zone or with surface runoff passing over the field edge (or down into surface water inlets within the field). Nitrogen and phosphorus that have passed the root zone or have been transported over the field edge can no longer be taken up by vegetation in the field and it is therefore no longer possible to manage by various agricultural cultivation measures, i.e. nitrogen and phosphorus have left the agricultural system. The nitrogen and phosphorus are then transported either down to deeper groundwater, which eventually reaches a watercourse, or to a drainage system for further transport into ditches and streams. During these transports, retention processes are carried out that reduce the amount of nitrogen and phosphorus that reach the watercourse. The extent of this retention depends on local conditions and varies greatly. In the method we describe in this report, the **nitrogen leakage** is represented by the leaching losses from the root zone from arable land. By contrast, the **phosphorus leakage** is represented by losses via both root zone leaching and surface runoff. These leakages of nitrogen and phosphorus can be considered as the gross leakage or gross load on waters from arable land.

To determine the size of the leakage losses of nitrogen and phosphorus from arable land, measurements are carried out in research projects and environmental monitoring programs. However, these are complex and costly and therefore cannot be carried out for all types of soils and climates or for all different crops and cultivation measures. To represent all arable land in Sweden, a very large number of combinations would be required. A different method is therefore required to estimate the total leakage from all arable land. Simulation models offer a conceptual and generalized description of nitrogen and phosphorus leakage and can therefore be used to calculate and analyze causes to leakage losses in a larger area, region or country.

For the purposes above, we have developed the NLeCCS (Nutrient Leaching Coefficient Calculation System) calculation system to calculate the nutrient leakage losses of nitrogen and phosphorus from arable land. The system is based on the mathematical simulation models SOIL/SOILN for nitrogen and ICECREAM for phosphorus, which are then connected to the simulation tools SOILNDB and ICECREAMDB, respectively. The models can calculate leakage of nitrogen and phosphorus for different types of soils, soil properties, climate, crops and cultivation measures, all these are important factors affecting the size of the nutrient losses. The models have been applied to a number of different leaching field trials under different conditions. During these tests, the models have been shown to be able to describe the leakage of nitrogen and phosphorus from Swedish arable land. The reliability of these applications, the calibrations performed and the parameter values determined form the basis to be able to use the models for general leakage calculations.

As mentioned earlier, leakage of nitrogen and phosphorus varies greatly from year to year, mainly due to a large variation in runoff, which in turn is due to varying weather conditions between years. Large runoff leads to large leakage of nitrogen and phosphorus while lower runoff leads to small losses. Determining nitrogen and phosphorus leakage for individual years and comparing them to determine the effect of changing cultivation measures on leakage can thus be severely misleading. Normalized climate and normalized runoff are thus a better basis for assessing the importance of cultivation for nutrient losses. In NLeCCS, we have therefore chosen to calculate nitrogen and phosphorus leakage from a longer period of weather data representing a normal climate and, based on this, calculate the multi-year average of the leakage or, as we have chosen to call it, **standard leakage rate** (in analogy with the annual standard harvests included in Sweden's official statistics). Thus, when comparing leakage calculated for different years, the effect of the weather can be "filtered out". As input to the calculations of the standard leakage rates using NLeCCS, we have used data on soil properties compiled for different regions based on national mappings and for data on crops, harvests, fertilization and other cultivation measures, we have chosen to use Swedish statistical data from Statistics Sweden and the Swedish Board of Agriculture.

By combining the estimated standard leakage rates for different combinations of soils, crops, soil phosphorus levels and gradients with geographical and statistical information on these factors, the gross load from arable land can be calculated for an area, region or whole country. These quantifications are used for reporting to international commissions on nutrient loads to the surrounding seas, for analysis of the impact of nutrients on our lakes and watercourses within the framework of the management of the EU Water Framework Directive (WFD), as part of the follow-up of the Swedish environmental objective 'No eutrophication' and for identifying the need for countermeasures. This has been carried out on a number of occasions, most recently in the calculations of nutrient pressures on the Baltic Sea and the West Sea in 2014 for reporting to HELCOM/PLC6 (Helsinki Commission, Pollution Load Compilation No 6) by The Swedish Agency for Marine and Water Management (Havs och vattenmyndigheten, 2016) where the load from agricultural land has been calculated for sub-catchment areas ("vattenförekomstområden"), river basins and regions/districts.

The present report provides a description of the NLeCCS calculation system and how it has been adapted to calculate nutrient leakage from Sweden's arable land for use in calculations of nutrient loads on Sweden's surrounding seas.

Development of the NLeCCS calculation methodology

The NLeCCS system originates from the Nordic project "Regionalization of erosion and nutrient losses from agriculture in Nordic countries" carried out in the 1990s (Rekolainen & Leek, 1996; Hoffmann & Johnsson, 1999). For nitrogen, the methodology was then used for calculating the load from southern Sweden on the West Sea and the Baltic Sea 1985-94 within the Swedish Environmental Protection Agency's study "Nitrogen from land to sea" (Environmental Protection Agency, 1997a,b; Johnsson & Hoffmann, 1997, 1998; Hoffmann & Johnsson, 2000).

The methodology was thereafter further developed, among other things, through a finer division of regions, use of the SOILNDB simulation tool (to administrate the SOIL and SOILN models), simulation of crop rotations, use of a new soil map, etc. The calculation system was then used for calculations of nitrogen standard leakage rates for the years 1995 and 1999 (Johnsson & Mårtensson, 2002). These calculations were carried out in the framework of the TRK project where the load of nitrogen on Sweden's surrounding seas was calculated and used for HELCOM/PLC4 reporting (Brandt

& Ejhed, 2002). The method was also used for river basin scale applications, scenarios for measures to reduce nutrient leaching and for climate scenarios (Kyllmar et al., 2002, 2005; Larsson et al., 2005; Arheimer et al., 2005; Blombäck et al., 2012). Subsequently, the system was further developed with regard to, among other things, crop management generation and the system was named NLeCCS (Nutrient Leaching Coefficient Calculation System). The system was then used to calculate the effect of the catch crop subsidy program on nitrogen leaching in 2001 (Johnsson & Mårtensson, 2006a), the change in nitrogen leaching between 1995 and 2003 (Johnsson & Mårtensson, 2006b) and the effect of changed crop fertilization rates on nitrogen leaching (Johnsson et al., 2006a). A new revised version of SOILNDB was developed in 2005 (Torstensson et al., 2006), and this was used for the first time in NLeCCS in calculations of standard leakage rates of nitrogen from organically cultivated farmland in 2003 (Johnsson et al., 2006b).

The system was then used for the calculation of standard leakage rates for 1999, 1995 and 2005 for use in the in-depth evaluations of the Swedish environmental target “zero eutrophication” and calculation of the load on the seas surrounding Sweden for reporting to HELCOM/PLC5 (Johnsson et al., 2008; Johnsson et al., 2009). For phosphorus, it was the first time the method was applied in the calculations for HELCOM/PLC5. For this purpose, NLeCCS was therefore further developed for phosphorus by connecting the ICECREAMDB model (Johnsson et al., 2006c). Subsequently, the same setup of the system has been used for calculations of the standard leakage rates of nutrients for 2009 (Blombäck et al., 2011) and for the year 2011 (Blombäck et al., 2014) for use in the follow-up of the environmental targets and for analysis of the causes to the change in nutrient leakage from arable land from 2005 and onwards. At the same time, the NLeCCS system has been further developed and a new version of the system was used for the calculation of the 2013 standard leakage rates. This latest version of the system is described in this report.

The NLeCCS calculation system

NLeCCS (Nutrient Leaching Coefficient Calculation System) is a system for calculating standard leakage rates of nitrogen and phosphorus from arable land. The system calculates the standard leakage in the form of leakage coefficients (mg/l or kg/ha) for a combination (matrix) of different regions, soils, crops and for phosphorus also field slope and soil phosphorus content. The calculated leakage coefficients can then be used to calculate the mean leakage rates (kg/ha) or the total leakage (tonnes) from arable land for different geographical scales. NLeCCS consists of a suite of computer programs (Persson et al., 2007a) whose output is used as an input for the next program (Figure 1). The computer programs manage databases, create input and output files for the simulation models and administrate a dynamic simulation of N and P in the soil growth system using these files. The various computer programs are described in summary below.

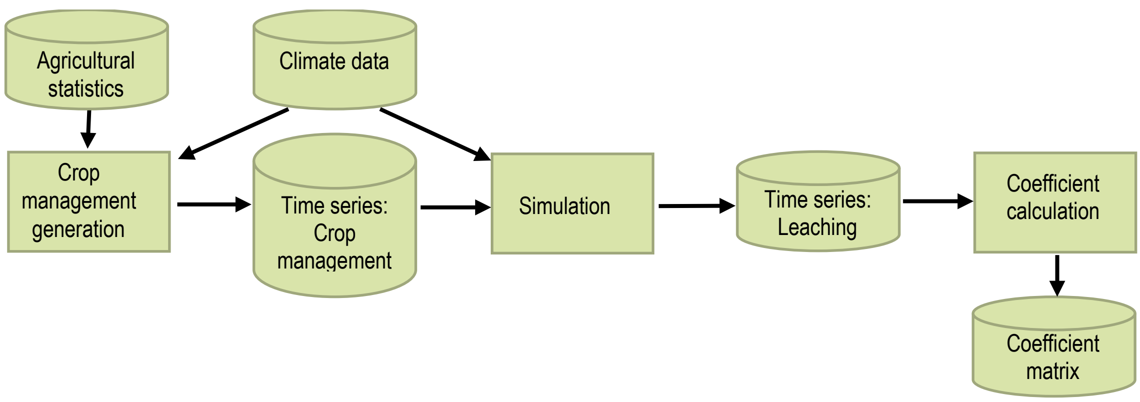

Figure 1. Flowchart of NLeCCS. Cylinders represent data and boxes represent calculation programs.

Crop Management Generation

Agricultural statistics for a specific year (the year for which a calculation is to be made) are compiled for each region in a database which is used as input for the program which generates time-series of crop management, CSMG (Crop Sequence Management Generator). The CSMG generates complete crop sequences including crop management that normally take place in crop cultivation, such as times of sowing, harvesting, fertilization, plowing and sowing of catch crops. The proportion of years that each crop occurs in the crop sequence is proportional to the areal coverage of that crop that year. The CSMG randomizes the crop sequence based on given rules for which crops can follow each other in a crop rotation. For example, that sugar beets cannot be followed by autumn wheat. The CSMG can generate very long crop sequences, in the order of 10,000's of years. In the simulation, the crop sequences are divided into 20-30 year time-series depending on how long a series of climate data you want to normalize. The long crop sequences are necessary so that all combinations of different crops, cultivation measures and meteorological conditions occur a sufficient number of times in the simulation to provide good averages of the leakage for each crop, particularly for crops with small areal coverage.

For each region for which calculations are to be made, climate data are compiled in a database together with information on the start and end dates of the growing season. The start date of the growing season is set as the date on which the average daily temperature is always above 4°C (daily mean temperature for 9 days). By analogy, the end date of the growing season is set as the date on which the average daily temperature drops below 4°C (Persson, 2016).

Simulation

The leakage of nitrogen and phosphorus is simulated with separate models. For nitrogen, the leakage is represented by total nitrogen leached from the root zone, which is simulated with the SOIL/SOILN model controlled by SOILNDB (see below). The calculations are made with the assumption of free drainage of the arable land at a depth of 1.5 m. Thus, drainage of all water leaving the root zone is calculated and can be said to be the sum of the water flowing down to deeper groundwater and to drainage pipes. SOILNDB reads the climate database and the cropping sequences from the CSMG and performs preparatory calculations, calculates parameter values for the SOIL/SOILN models and starts the simulations. After the SOIL/SOILN model simulations, SOILNDB compiles the results into time series with annual averages for agro-hydrological years, July 1 to June 30. This means that the leaching of N from the crop growing in the field on 1 July is attributed to the leaching occurring during the agro-hydrological year lasting from July 1 to June 30 the following year. The reason for this is that the crop affects the size of nitrogen leaching losses occurring after the growing season during the coming discharge period from autumn to spring.

The phosphorus leakage is simulated with the ICECREAM model controlled by ICECREAMDB (see below) which reads the climate database and cropping sequences from the CSMG. After the ICECREAM simulation, ICECREAMDB compiles the result into time series with annual averages for calendar years. This means that the leakage of phosphorus throughout the calendar year is attributed to the crop harvested that year. The reason for this is that the crop mainly affects the size of phosphorus leakage losses during the growing season. For phosphorus, the leaching is divided into leaching from the root zone and losses through surface runoff and these in turn are divided into a dissolved (SRP) and a particulate (PP) fraction. The simulations of the time series with nitrogen and phosphorus are made for all soil types in each region (with associated climate and agricultural statistics). For phosphorus, simulations are also made for different soil phosphorus levels and different field slopes for each soil type and region.

Coefficient calculation

Based on the estimated annual averages, multi-year averages of leakage are calculated for all different combinations of crops and soils in each region, resulting in a matrix of coefficients. For phosphorus, the field slope and the soil phosphorus content are also included in the matrix, and for the dependence of leakage on these vectors, leakage equations are created. This is done by calculating coefficients for a few different field slopes and phosphorus concentrations and then calculating leakage equations using linear multiple regression (Persson, 2009) with slope and soil phosphorus as independent variables and phosphorus loss as dependent variables. The leakage coefficients represent the average of all years with a given crop in the crop sequence and are expressed in kg/ha*yr or mg/l*yr. The leakage coefficients include effects of weather, crop and fertilization combinations, tillage time points and possible catch crops and buffer zone effects.

The models

SOILNDB (nitrogen)

SOILNDB (Johnsson et al., 2002; Larsson et al. 2002; Torstensson et al., 2006) is a model for calculating nitrogen leaching from arable land with simplified input requirements (Figure 2). The program is structured as a "shell" around a previously developed research-oriented model for nitrogen leaching from arable land (SOIL-SOILN, see below) and a parameter database. The choice of cropping systems (crops, harvests and crop management), soil type and climate are linked to procedures for automatic parameterization of the model based on the values in the parameter database. SOILNDB can reduce the work- and time-consuming operations related to parameter setting, running the model and presentation of results, which enables relatively effective calculations for many different cultivation situations. One or more fields with several years of cultivation can be calculated in a sequence.

The input required for a calculation is less detailed and less comprehensive than required for direct use of SOIL and SOILN. A database containing parameter values (for example soil properties) specific to the SOIL and SOILN models is included in the system. These values are based on previous tests and applications of the models. In addition, calculation procedures to estimate parameter values are also included. SOIL and SOILN are connected in series in the system, that is, the output from the SOIL model automatically constitutes input to SOILN. Presentation of the simulation result in summarized form is also included in the system.

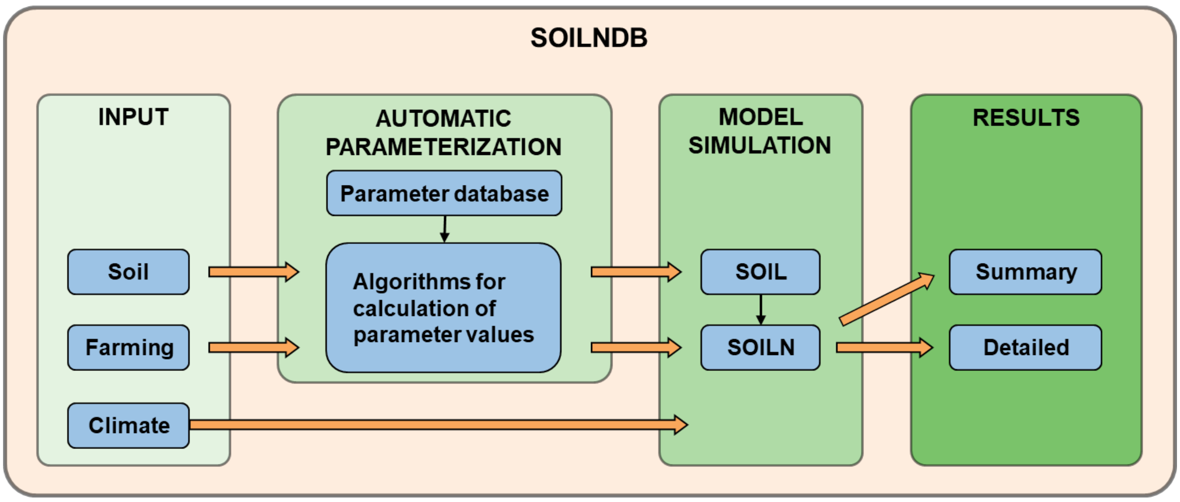

Figure 2. Schematic description of SOILNDB.

SOIL-SOILN

In the mid-1980s, the simulation model SOILN (Johnsson et al., 1987) was developed at the Swedish University of Agricultural Sciences (SLU). The model, which describes the dynamics and losses of nitrogen in arable land (Figure 3), was linked to a previously developed water and heat model, SOIL (Jansson & Halldin, 1980; Jansson, 1991). The aim of this work was to increase understanding of how the simultaneous physical and biological processes in the soil-plant system affect the losses of nitrogen with varying weather, soil types, cropping systems and crop management. To make the model applicable to different sites, the structure of the model was made simple and its input needs were adapted to a level that would correspond to what is normally available in field trials.

The SOIL model is a physically based model for water and heat flow in a soil profile and includes functions for snow dynamics, soil frost, evapotranspiration, infiltration, surface run-off and drainage flows to drainage systems and groundwater as well as plant water uptake. As input, the model uses time series of standard meteorological data, such as air temperature and precipitation, solar radiation, wind speed and air humidity. The SOIL model provides the SOILN model with driving variables, i.e. time series of infiltration, water flows between soil layers and to drainage pipes, soil water content and soil temperature in different soil layers. The SOILN model uses the driving variables from the SOIL model to calculate time series of nitrogen leaching from the root zone to drainage pipes and groundwater. The SOILN model includes functions for the main processes that control the flow and state of nitrogen in agricultural land such as; inflow of nitrogen through manure and mineral fertilization and deposition, mineralization of organic nitrogen to ammonium and nitrate dependent on soil temperature and moisture, decomposition of plant residues to carbon dioxide and humus, plant nitrogen dynamics such as root uptake of nitrogen to plants, harvest and the return of dead plant residues to the soil, denitrification depending on soil temperature, oxygen status and nitrate content, and nitrate transport in the soil profile and in the drainage water.

The model, gives typical representativeness for a reasonably homogeneous agricultural field, and is thus particularly suitable for examining the influence of different crop management practices, climates and soil types on root zone leaching (i.e. losses from the soil-plant system which is affected by different crop management practices).

The model has been tested on several different field experiments (see compilation in, for example, Hoffman, 1999). It has also been used to estimate leaching from fields where only a limited amount of input data is available and for simulation of various possible cultivation measures to reduce leaching of nitrogen from arable land. The tests have shown that the model can describe the variation of mineral nitrogen in the soil and nitrogen leaching for different soils, cropping systems and climates in Sweden. By testing the model using different datasets, we increase our knowledge of its generality and our knowledge to parameterize it. We also gain knowledge about the sensitive parts of the model and how we can improve it. The process of testing the model is thus ongoing. This makes it possible to apply the model with increased precision to sites where only a very limited amount of input is available.

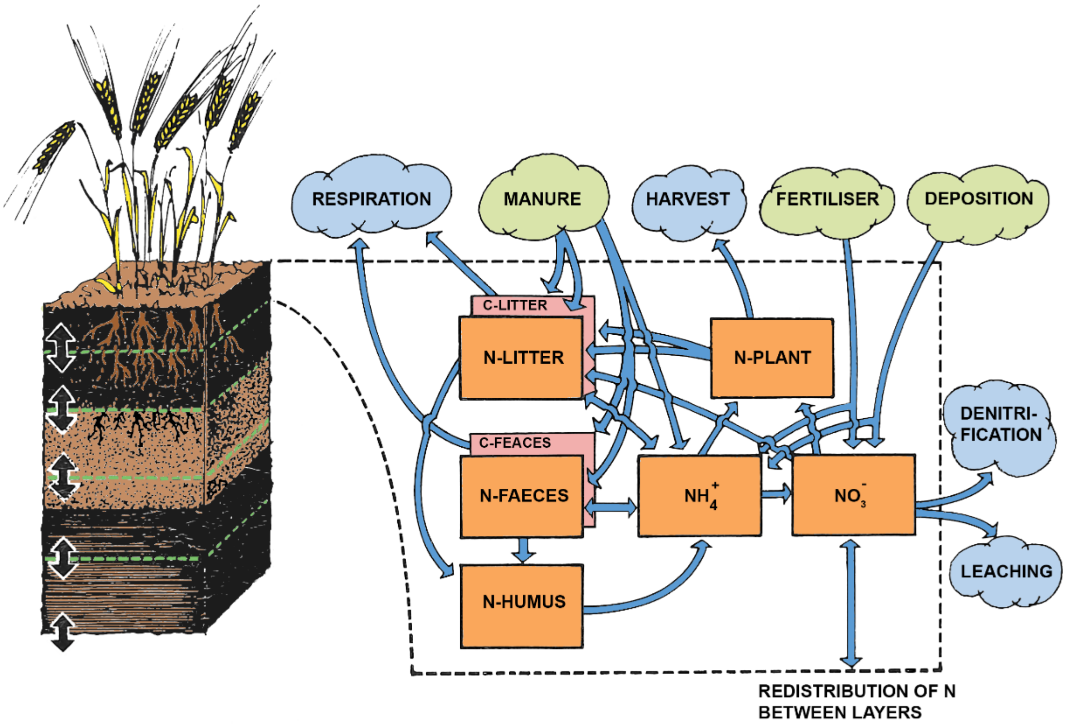

Figure 3. Structure of the SOILN-model (after Johnsson et al., 1987)

ICECREAMDB (phosphorus)

ICECREAMDB (Persson et al., 2007b) is a model for calculating phosphorus losses from arable land from larger areas based on the ICECREAM model (see below). The calculations are made easier compared to ICECREAM as large amounts of input and results can be handled rationally. ICECREAMDB reads all the data needed to run ICECREAM from databases and converts them into the text files that ICECREAM is controlled with. With ICECREAMDB, it is therefore possible to conduct thousands of simulations in succession. The results from ICECREAMDB are automatically processed so that leakage coefficients (annual averages) for each combination of soil type, crop, slope, soil phosphorus content and fertilization regime are generated from the daily simulation results.

ICECREAM

ICECREAM is a dynamic, partly physically based, crop management-oriented phosphorus leakage model (Rekolainen & Posch, 1993; Tattari et al., 2001; Larsson et al., 2007; Radcliffe et al., 2015). ICECREAM can calculate the influence of different crop cultivation measures on water flows, erosion and loss of dissolved (SRP, Soluble Reactive Phosphorus) and particular (PP) phosphorus via surface run-off and leaching through the soil profile from a field (Figure 4). The model, originating from the EPIC models (Jones et al., 1984, Sharpley et al., 1984) and CREAMS (Knisel, 1980), was then further developed in Finland to describe phosphorus losses under Nordic climatic conditions (Posch & Rekolainen, 1993; Rekolainen & Posch, 1993; Tattari et al., 2001). Since leaching through the soil profile via macropores is an important loss path for phosphorus in many Swedish arable soils, the model has been further developed to include it in the calculations (Larsson et al., 2007). The model was parameterized for Swedish conditions (Johnsson et al., 2006c) and was first used for PLC5 reporting (Johnsson et al., 2008). Several sensitivity analyses of the model have been done to obtain knowledge of which parameters should be chosen with greater accuracy (Bärlund and Tattari, 2001; Johnsson et al., 2006c; Larsson et al., 2007; Djodjic et al., 2008; Blombäck and Persson, 2009; Schmieder et al., 2010).

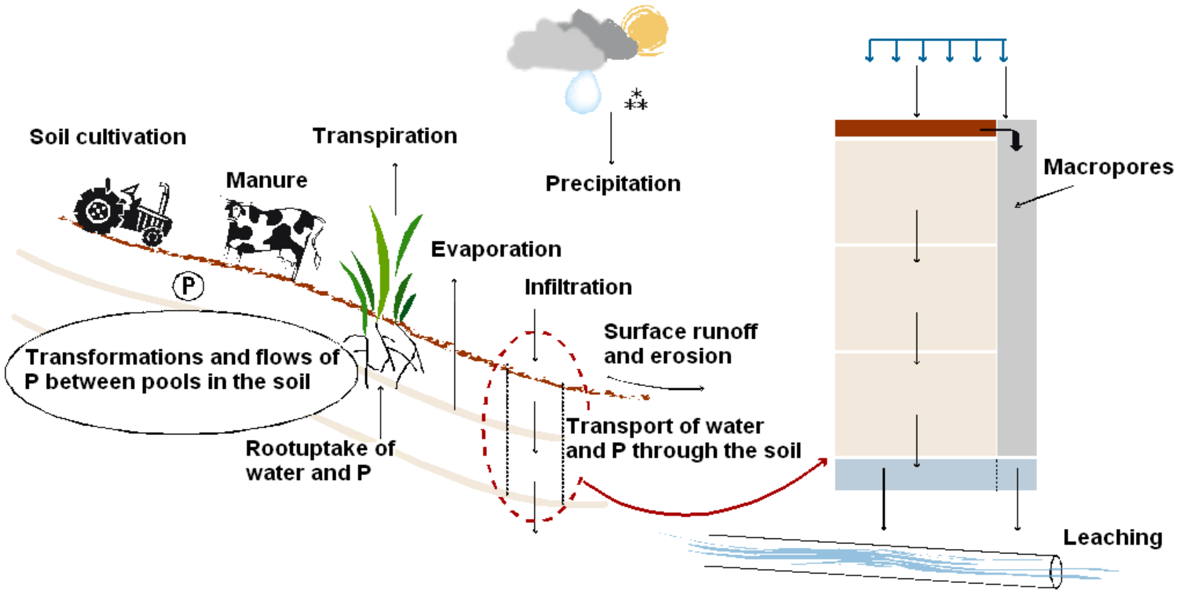

Figure 4. ICECREAM overview (after Bärlund & Tattari, 2001).

ICECREAM calculates flows and changes in pools with daily resolution and as driving data, meteorological data are used for temperature, precipitation, and cloudiness or solar radiation with the same time resolution. The soil profile is divided into different layers, each layer containing pools of ground water and different forms of mineral-bound and organically bound phosphorus (Figure 5). The model calculates plant uptake, mineralization, immobilization and humification as well as losses of SRP and PP via surface runoff, macropore flow and with percolating water through the soil profile. The calculations take into account different tillage measures and how they affect soil surface roughness and how organic matter and manure are mixed in the soil.

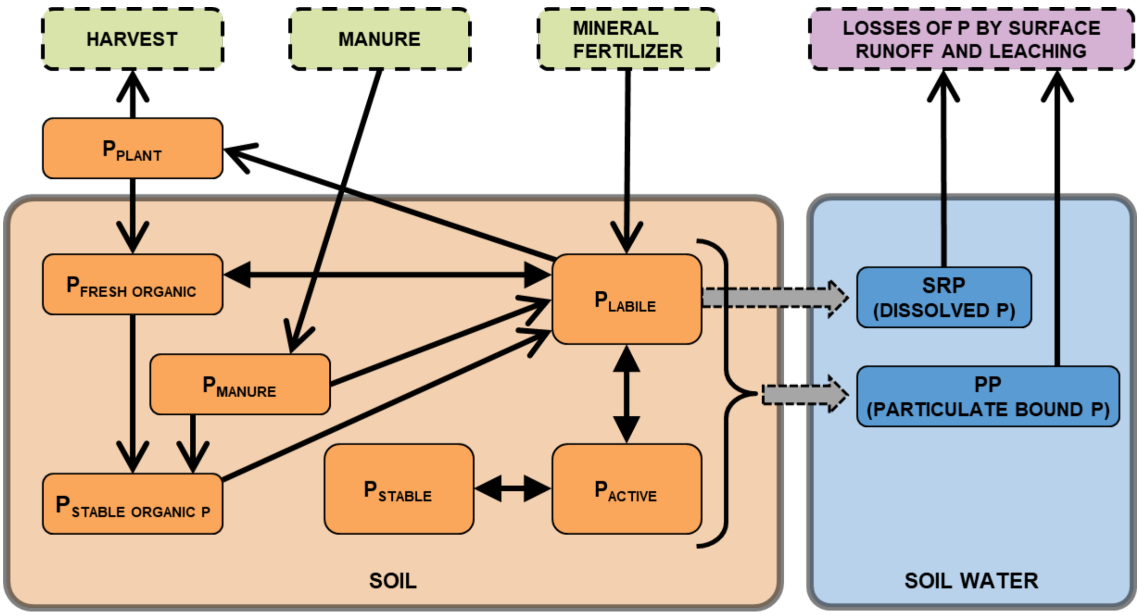

Figure 5. Pools and flows of phosphorus calculated using ICECREAM.

Since the calculation of phosphorus losses is highly dependent on the geometric shape of the field, both the slope of the field and its length along the slope direction (slope length) are taken into account in the calculation of surface run-off and erosion as well as the surface losses of SRP and PP (Figure 6).

To calculate the impact of buffer zones, the area of the field can be divided into two segments where the upper segment represents the cultivated crop in the field and the lower represents the buffer zone (Figure 6).

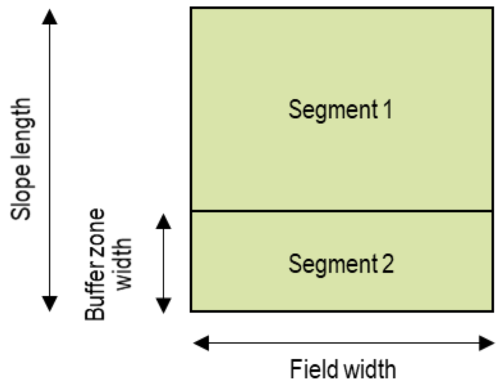

Figure 6. Definition of the dimensions and areas of the calculated field.

Applications of NLeCCS - nutrient leakage from arable land in Sweden

Calculations of standard nutrient leakage rates from Swedish arable land have been carried out using NLeCCS methodology for the years 1995, 2000, 2005, 2007, 2009, 2011 and 2013 (Johnsson et al., 2008; Johnsson et al., 2009; Blombäck et al., 2011; Blombäck et al., 2014; Johnsson et al 2016). Below is a summary description of the calculation for 2013 (Johnsson et al., 2016) which has been used for the calculations of nutrient loads on the Baltic Sea and the North Sea in 2014 for reporting to HELCOM-PLC6 (Havs och vattenmyndigheten, 2016). The full description can be found in Johnsson et al. (2016).

The Matrix - Combination of factors that affect the estimated leakage

Calculations of standard leakage of nitrogen and phosphorus in 2013 in the form of coefficients were performed for a matrix of the constituent vectors:

- Leakage region (22)
- Crop (13)
- Soil (10)
- Soil phosphorus in topsoil (only for phosphorus)
- Slope (only for phosphorus)

Leakage regions

Arable land in Sweden was divided into 22 leakage regions (Figure 7, Table 1). The basis for the division was Statistics Sweden's division into eighteen production areas (PO) for the reporting of agricultural statistics, of which four of these production areas were in turn divided due to large climate differences within the region. Each leakage region was assumed to have a characteristic annual discharge, used as "target discharge" in the calculations, and a climate station representative of the region.

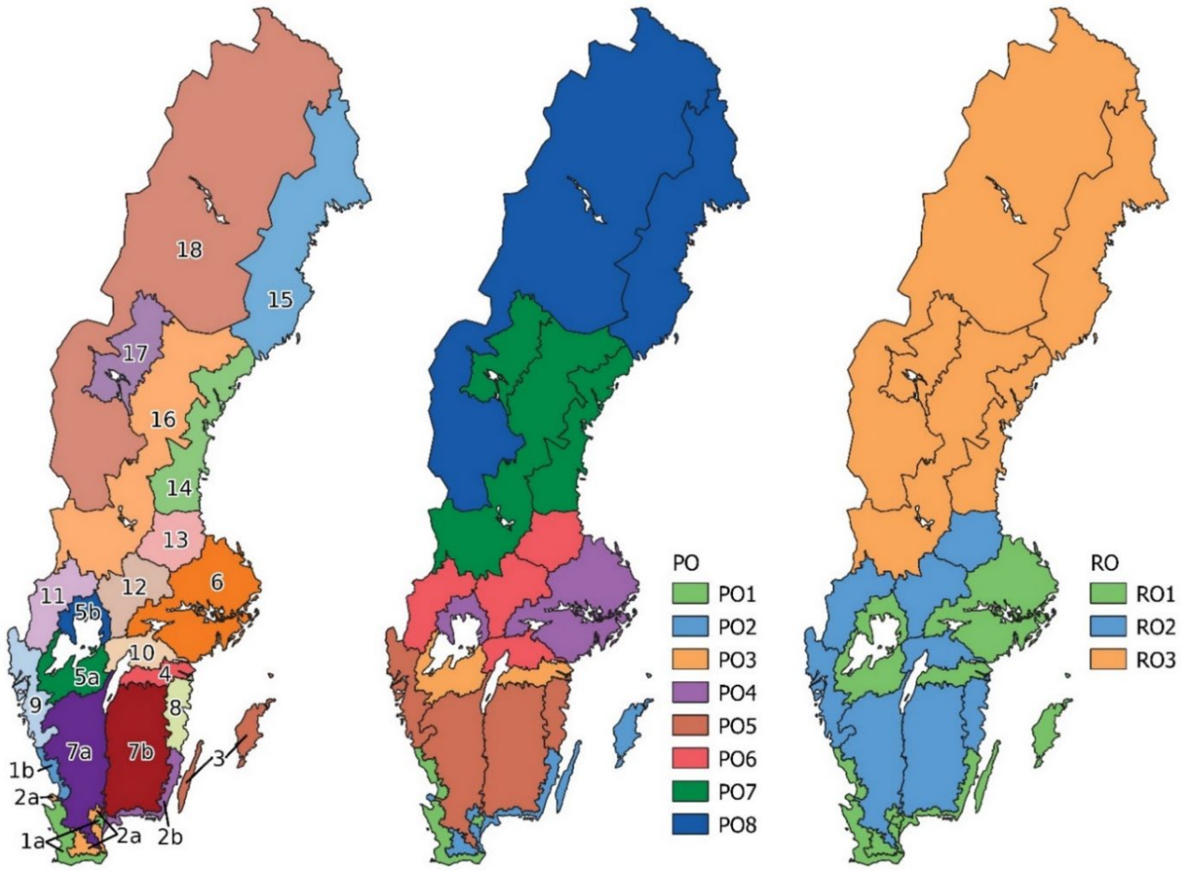

Figure 7. Leakage regions (Lr), production areas (PO8) and national areas (RO) in Sweden.

Table 1. Leakage regions (Lr), production areas, national areas.

Lr	Production area, PO18, no	Production area, PO8, no	National area, RO, no
1a	Skåne-Hallands slättbygd, 1 (Skånedelen)	Götalands södra slättbygder, 1	Södra & mellersta Sveriges slättbygder, 1
1b	Skåne-Hallands slättbygd, 1 (Hallandsdelen)		
2a	Sydsvenska mellanbygden, 2 (Skånedelen)	Götalands mellanbygder, 2	
2b	Sydsvenska mellanbygden, 2 (Blekinge-Kalmardelen)		
3	Öland & Gotland, 3		
4	Östgötaslätten, 4	Götalands norra slättbygder, 3	
5a	Vänerslätten, 5 (Södra delen)		
5b	Vänerslätten, 5 (Norra delen)	Svealands slättbygder, 4	
6	Mälar- & Hjälmarbygden, 6		
7a	Sydsvenska höglandet, 7 (Västra delen)	Götalands skogsbygder, 5	Södra & mellersta Sveriges skogs- & dalbygder, 2
7b	Sydsvenska höglandet, 7 (Östra delen)		
8	Östsvenska dalbygden, 8		
9	Västsvenska dalbygden, 9		
10	Södra Bergslagen, 10	Mellersta Sveriges skogsbygder, 6	
11	Västsvenska dalsjöområdet, 11		
12	Norra Bergslagen, 12		
13	Östra Dalarna, 13		
14	Kustlandet i nedre Norrland, 14	Nedre Norrland, 7	Norra Sverige, 3
15	Kustlandet i övre Norrland, 15	Övre Norrland, 8	
16	Nordsvenska mellanbygden, 16	Nedre Norrland, 7	
17	Jämtländska silurområdet, 17	Nedre Norrland, 7	
18	Fjäll- & moränbygden, 18	Övre Norrland, 8	

Soils

The calculations were carried out for ten soils according to the international FAO texture classification system (Figure 8). These soils were sand, loamy sand, sandy loam, loam, silt loam, sandy clay loam, clay loam, silty clay loam, silty clay and clay. The soils differ for example in terms of hydraulic properties, erosion sensitivity (phosphorus) and maximum root depth.

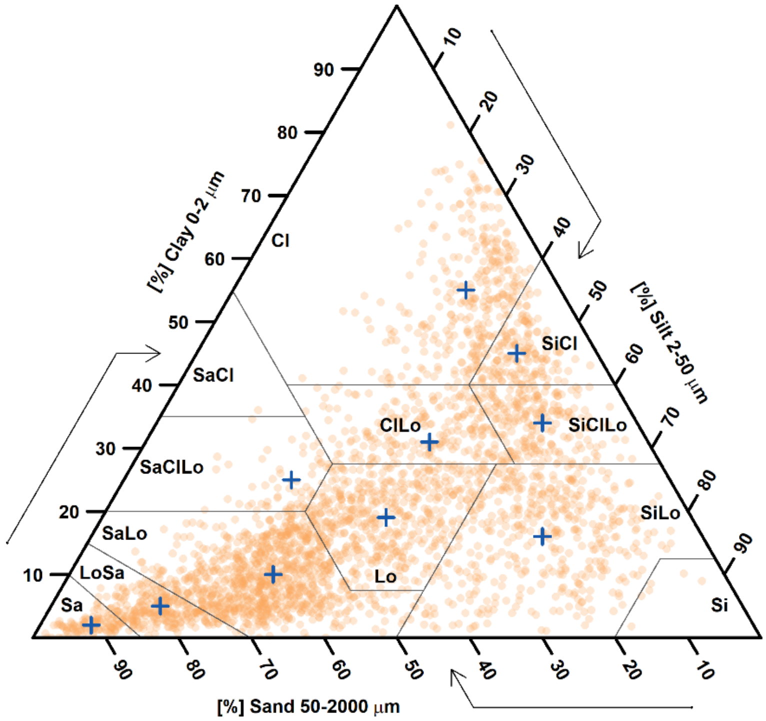

Figure 8. Soil texture triangle with medium textures (+) for the different texture classes based on a land mapping of Swedish arable land conducted by Eriksson et al. (1999). The number samples in the mapping was 3034. The samples are represented in the triangle as orange points. Soil texture shortenings; Sa-Sand, LoSa-loamy sand, SaLo-sandy loam, Lo-loam, SiLo-silt loam, SaClLo-sandy clay loam, ClLo-clay loam, SiClLo-silty clay loam, SiCl-silty clay, Cl-clay.

Crops

The calculations were carried out for thirteen crop classes: spring barley, winter wheat, spring wheat, grass ley, sugar beet, winter rape, spring rape, potatoes, corn, rye, oats, fallow and extensive grassland. Only crops grown on more than 1 % of the arable area in each leakage region were included in the estimated crop sequence.

Soil phosphorus in topsoil and slope

For each region, phosphorus leakage was calculated for three different phosphorus levels in the topsoil and for three different slopes (10 and 90 percentile and average for each region respectively). Based on these calculated values, leakage equations were created for the phosphorus leakage's dependence on the phosphorus content and slope of the soil (Persson, 2009). Using these equations, phosphorus leakage can be calculated for any given value of the soil phosphorus content and slope of the different combinations of leakage region, crop and soil type.

The cropping system

The simulated cropping system is based on statistical data from Statistics Sweden and the Swedish Board of Agriculture on crops and cultivation measures for the different production areas in Sweden. Crop sequences with a length of 15,000 years were created for each leakage region with the crop sequence management generator CSMG (see description of NLeCCS). Extensive grassland was not included in the crop sequence but was calculated separately. The crops have been fertilized in two ways (below referred to as fertilization regimes); manure fertilization with complementary mineral fertilization and only mineral fertilization. In the phosphorus calculation, the crops have also been able to be unfertilized.

For each leakage region, the crop sequences have been randomized based on statistical data for 2013 so that:

- The crops have occurred in proportion to the proportion of area of different crops.
- Manure fertilization has occurred in proportion to the proportion of the crop area that has received manure.
- Mineral fertilization has occurred in proportion to the proportion of the crop area that received mineral fertilizers.
- No fertilization (included only in the phosphorus calculation) has occurred in proportion to the proportion of the area of the crop not fertilized with phosphorus.
- Manure fertilization in the autumn occurred in proportion to the proportion of the manure-fertilized area that was fertilized in autumn and manure fertilization in the spring was proportional to the proportion of the manure-fertilized area that was fertilized in spring (for ley in the phosphorus calculation also manure fertilization in the summer in proportion to the proportion of area that was fertilized in summer).
- Catch crop has occurred in proportion to the proportion of the area of each crop sown with catch crop.
- Soil cultivation in spring has occurred in proportion to the proportion of the area of spring-sown crops having soil cultivation in spring.
- Harvest of straw occurred in proportion to the proportion of the area of each crop where straw was harvested.

The crop sequence for each leakage region thus included all possible combinations with respect to crops, fertilization dates, straw harvest, fertilization regimes, tillage dates and catch crops.

The crops were randomized to follow each other according to certain restrictions. The restrictions were made to take into account, for example, plant protection and the different harvest and sowing dates of crops (Table 2). Autumn sown crops, for example, have not been able to follow sugar beets because sugar beets are harvested so late in the autumn. Grass ley has not been able to follow potatoes and sugar beets because the harvest of these two crops make it impossible to have grass undersown. Catch crop could not be followed by autumn-sown crop or grass ley. The perennial grass ley was established by sowing in into another crop and starting to grow after the harvest of this main crop. The number of years with grass ley before breaking the ley was based on crop management statistics on ley age. The crop sequence included only the area of temporary grass ley, i.e. grass ley that is harvested each year and plowed up at regular intervals. Grass leys for grazing and long-term fallow were not included in the crop sequence, but were assumed to be permanent plant species (unplowed) found on the same land for several years (the leakage for these was assumed to be equal to the leakage for grass ley followed by grass ley, i.e. a grass ley without breaking the ley in autumn). The area of fallow was divided into stubble fallow and green fallow (both of which were included in the crop sequence) and long-term fallow. The same crop sequence has been used for all soil classes within the respective leakage region.

Three types of catch crops and spring soil cultivation were included in the crop sequence:

- Undersown catch crop that is plowed in the spring of the following year
- Undersown catch crop that is plowed in the autumn and
- Spring plowing with "catch crop" consisting of waste grain and weeds.

Table 2. Possible and impossible crop combinations in the crop sequences and crop combinations possible with catch crops and/or soil cultivation in spring. Black squares symbolize crop combinations that were marked in the crop generator as being impossible to appear, dark gray squares symbolize possible combinations but marked in the crop generator as less likely and white and green squares symbolize possible crop combinations. Green squares are combinations that are possible with catch crop and/or soil cultivation in spring.

Crop	Following crop												
	Spring barley	Winter wheat	Grass ley	Sugar beets	Winter rape	Oats	Spring wheat	Rye	Spring rape	Potato	Green fallow	Stubble fallow	Maize
Spring barley													
Winter wheat													
Grass ley													
Sugar beets													
Winter rape													
Oats													
Spring wheat													
Rye													
Spring rape													
Potato													
Green fallow													
Stubble fallow													
Maize													

Simulation and coefficient calculation

The 15,000-year long crop sequences for each leakage region were divided into datasets (time series) that were 30 years long for which leakage calculations were performed using the 30-year climate data series representative for each region. For each leakage region the crop sequence was simulated for all soil types (N and P) as well as for all combinations of the three different soil phosphorus levels and the three different slopes (P only). Averages for the individual crops were calculated for each combination of soil and leakage region (N and P) and slope and soil phosphorus levels (P) based on the individual annual leakage values within the time series. For phosphorus, these means were used to make soil phosphorus and slope-dependent leakage equations for each combination of soil type, crop and leakage region. One final step was to make coefficients for crops that were not simulated. This was done by assigning the leakage coefficients of these missing crops average values from simulated crops with similar characteristics.

Input data and assumptions

The parameterization of the SOILNDB and ICECREAMDB models was mainly based on previous applications of these models (See above in Introduction: development of the calculation methodology and in Johnsson et al, 2016 for detailed description of parameterization).

Soil

In the nitrogen calculations it was assumed that the organic pool of the arable soils (soil organic matter content) was in balance in all leakage regions, i.e. that there was neither a build-up nor reduction in the amount of organic nitrogen in the arable soil on average for the leakage regions during the calculation period. The reason for this assumption was partly that we do not know whether current cropping (as reported in statistical data for 2013) leads to an increase, decrease or unchanged soil content, and partly, that the organic pool should generally have reached a state of balance since agriculture has been conducted in a relatively similar way for a long time. In order to achieve balance in the soil's organic N-pool in the simulations, the mineralization of organic nitrogen (humus-N pool) in the soil has therefore been adjusted for the different leakage regions.

For the phosphorus calculations, the hydrological properties of the soil as well as the properties that regulate phosphorus solubility are crucial. For the chemical properties, it was assumed that all fields in Sweden behave in a similar way in terms of sorption and solubility of mineral phosphorus. This means that the calculations do not represent soils with very high and very low phosphorus sorption ability, but represent an average field. For the hydrological properties, each soil type has been assumed to have specific characteristics and the parameterization of the soil properties of these was made based on independent pedotransfer functions (Rawls et al, 1982). Erosion sensitivity to surface runoff was also independently parameterized to be soil-specific. In contrast, the parameter values for how particles transported in macropores are released were calibrated. The calibration was made using measurement data on phosphorus losses from observation fields (Stjernman et al., 2015). The dimensions of the field sizes in the different regions were calculated using the average of each region's block size (the Swedish Board of Agriculture's block database for 2014) and an assumption of square shape in the fields. To calculate the slope of the fields in the different regions, data from *lantmäteriet's* "GSD-Höjddata 2+" (Lantmäteriet, 2015) was used (Figure 9, Figure 10). In the calculation, soil mapping data of phosphorus levels extracted by 2 molar hydrochloric acid (P-HCl; KLS, 1965) in the topsoil have been used as inputs to describe the soil's stores of mineral phosphorus (Eriksson et al. 1997, 2010; Djodjic & Orback, 2013) (Figure 9, Figure 10).

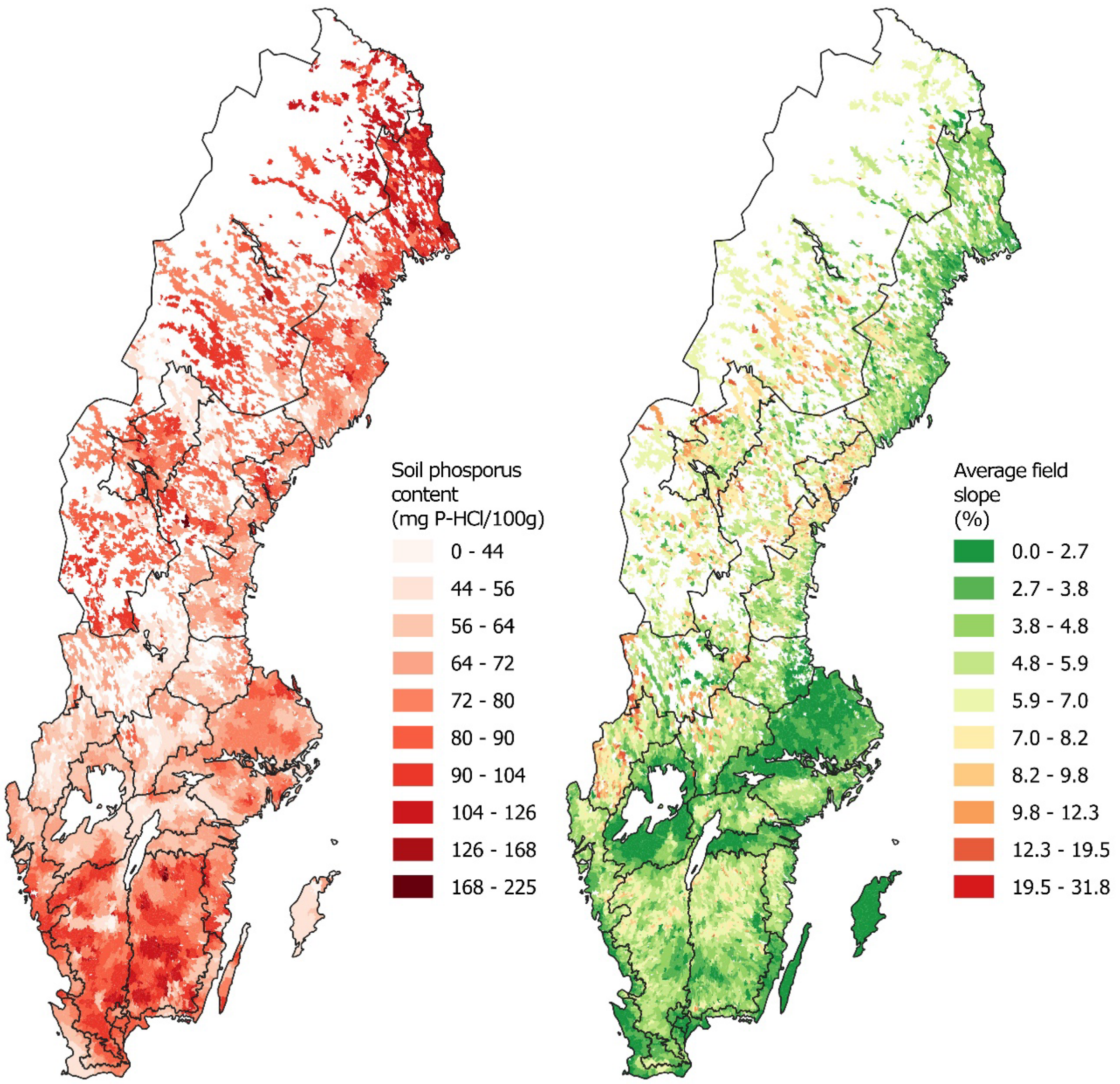

Figure 9. Slope of the fields and phosphorus concentrations in soils in the different sub-catchment areas.

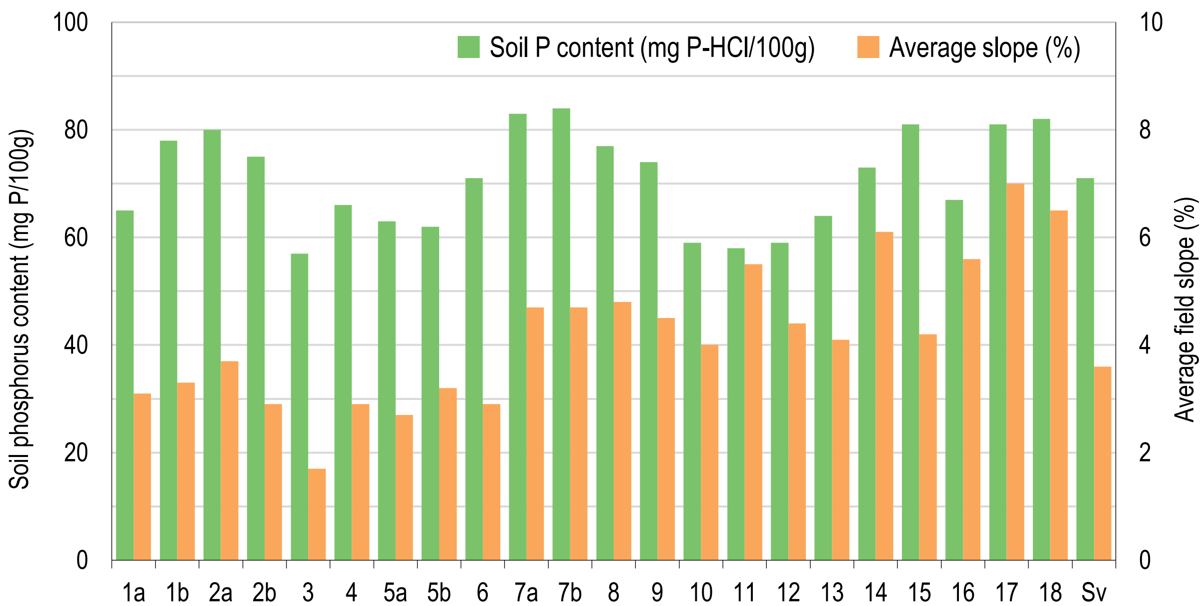

Figure 10. Average slope of fields and phosphorus concentrations in soils (area-weighted averages) used for the calculations in the leakage regions (Lr) and for Sweden on average (Sv).

Distribution of soil textures

The distribution of soil textures (Figure 11) used in the calculations for the arable land has its origins in a national soil mapping of arable land (Djodjic, 2015; Jordbruksverket, 2015) but has been further processed for the needs of this project (Widén-Nilsson et al., 2016).

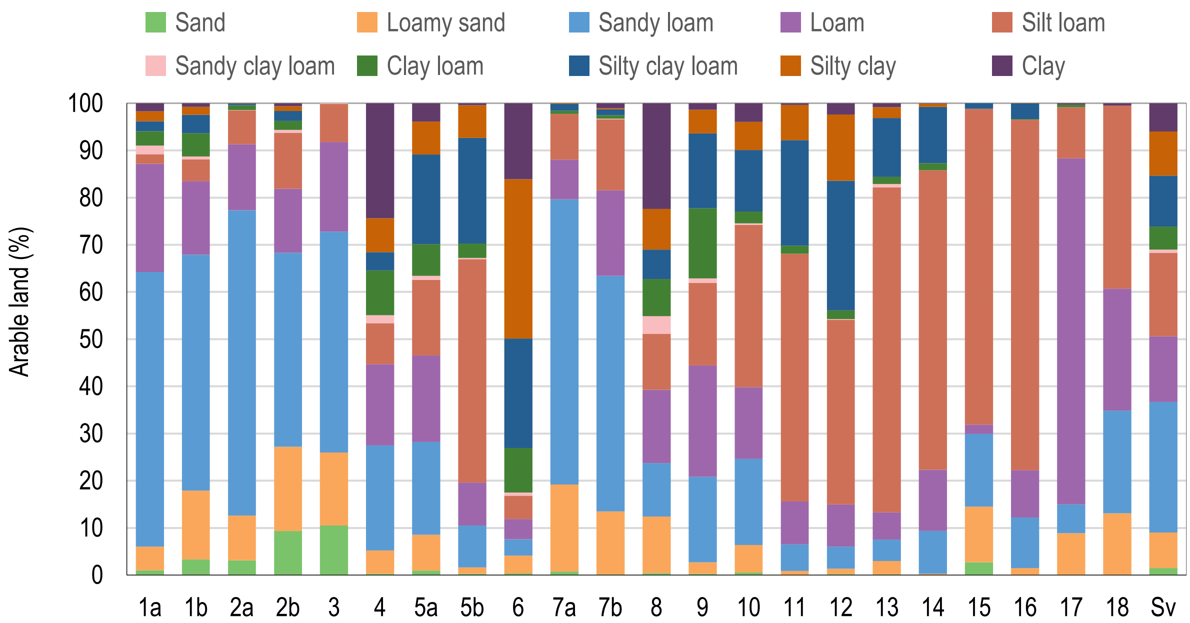

Figure 11. The textural distribution of the ten soils used in the calculation for arable land in the leakage regions and for Sweden on average (Sv).

Discharge and climate

Precipitation from the climate stations of the different regions has been adapted so that the simulated discharges for the leakage regions (root zone drainage for nitrogen and root zone drainage + surface run-off for phosphorus) have been consistent (+/- 0,5 mm) with the target discharge for each leakage region. For the calculations, meteorological data for the period 1984 to 2014 have been used from the respective climate station, which was considered long enough to represent a normal climate.

Target discharge (annual discharge for agricultural land; Figure 12, Figure 13) in each leakage region was calculated using GIS (Widén-Nilsson et al., 2016). This was done by using the estimated average discharges for sub-catchment areas in Sweden for the period 1994-2013 made for the load calculations for HELCOM/PLC6 (Tengdelius-Brunell et al., 2016a), digital maps of agricultural land (block map) and a digital map of the 22 leakage regions.

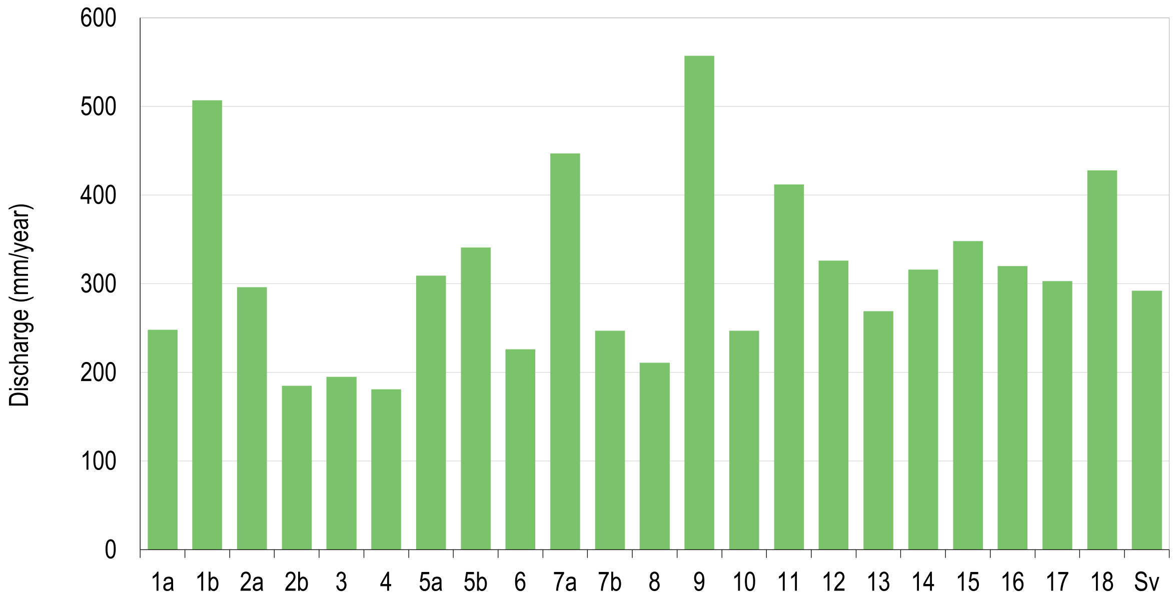

Figure 12. Discharge (average for the period 1994-2013) for arable land in the leakage regions and for Sweden in average (Sv).

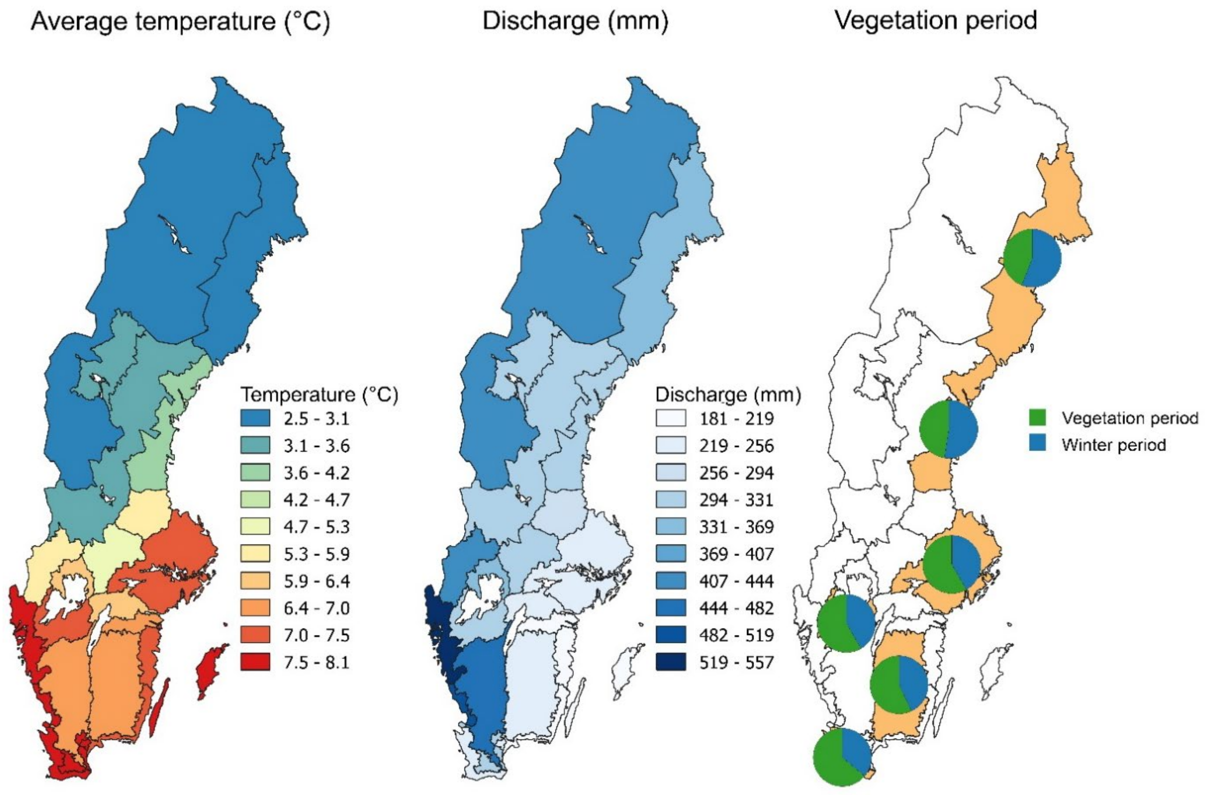

Figure 13. Annual average temperature (ºC), discharge (mm/year) and the relative length of vegetation periods of some selected leakage regions.

Crop areas

The crop distribution for the twelve crop classes included in the crop sequence (Figure 14) was calculated on the basis of crop areas compiled by Statistics Sweden from the Farm Register (Lantbruksregistret, LBR) 2013 (which in turn is based on data from the Swedish Board of Agriculture's administrative register for area-based subsidies) and with additional data on grass ley and fallow from the fertilizer survey (gödselmedelsundersökningen) 2013 (SCB, 2014) and the survey on cultivation measures (odlingsåtgärder) 2012 (SCB, 2013a).

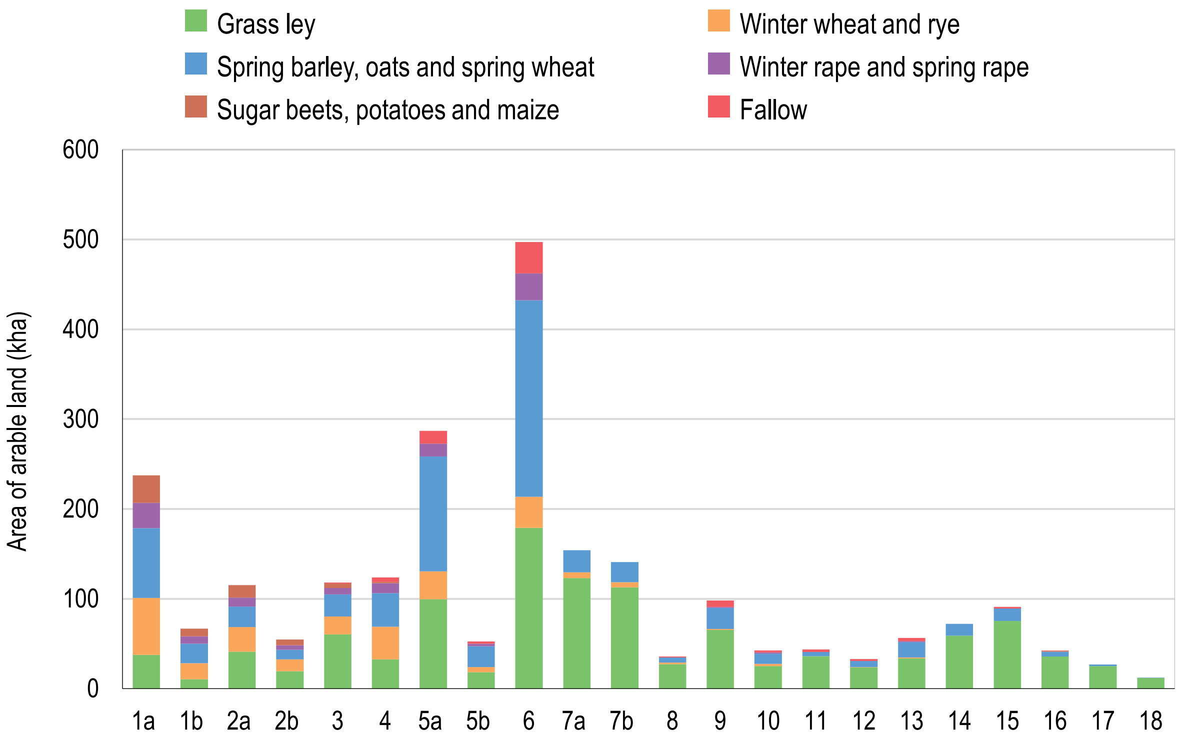

Figure 14. Total areas of the 12 crop classes included in the crop sequences for each leakage region used in the calculation of standard leakage rates for 2013.

.

Fertilization, N-fixation and deposition

For fertilization, we have chosen to use statistical data for the fertilizer use of the current calculation year (Statistics Sweden) assuming that fertilization always takes place for the expected harvest yield, the standard yield (used as input; see below the section "harvests"). Fertilization statistics for nitrogen and phosphorus (applied amount of mineral fertilizer and manure, proportion of fertilized area and spreading date for manure) for the different crops were compiled for the leakage calculation for 2013 by Statistics Sweden for different regional levels (PO18, PO8, RO, Riket) based on data from the Fertiliser Survey 2013 (SCB, 2014). The fertilization statistics were used with as high regional resolution as possible, i.e. where statistics from the PO18 level were missing, supplementation from the nearest higher regional level with available statistics was made. Stubble and green fallows were not fertilized.

Statistics Sweden reports fertilization in four fertilization classes: only mineral fertilizer, only manure, mineral and manure fertilization and no fertilization. The only mineral fertilization class has formed the basis for the fertilization regime *only mineral fertilization* in the calculations. The only manure fertilization class and the mineral and manure fertilization class have been merged into the fertilization regime *manure fertilization with supplementary mineral fertilization* in the calculations. For nitrogen, the area not fertilized at all with nitrogen has been distributed proportionally between the two fertilization regimes in order for all crop area to be covered by the two fertilization regimes. However, areas not N-fertilized represented only a small proportion of the total cropped area. For phosphorus, the no fertilization class constituted its own fertilization regime. The unfertilized area was significant for phosphorus and represented about one third of the total arable area (Figure 15). For the fertilization regime *only mineral fertilization*, fertilizer has been applied once in the spring. For the fertilization regime *manure fertilization with supplementary mineral fertilization*, the entire amount was spread either in the autumn or in the spring/summer.

Data on nitrogen fixation for grass ley and green fallow were compiled for this calculation by Statistics Sweden for different PO8 regions based on calculations of nutrient balances for agricultural land in 2011 (SCB, 2013c). The deposition of nitrogen was based on mean values from grid-based calculations for Sweden for the years 2005-2012 (MATCH model) carried out by SMHI for this calculation. No phosphorus deposition was assumed.

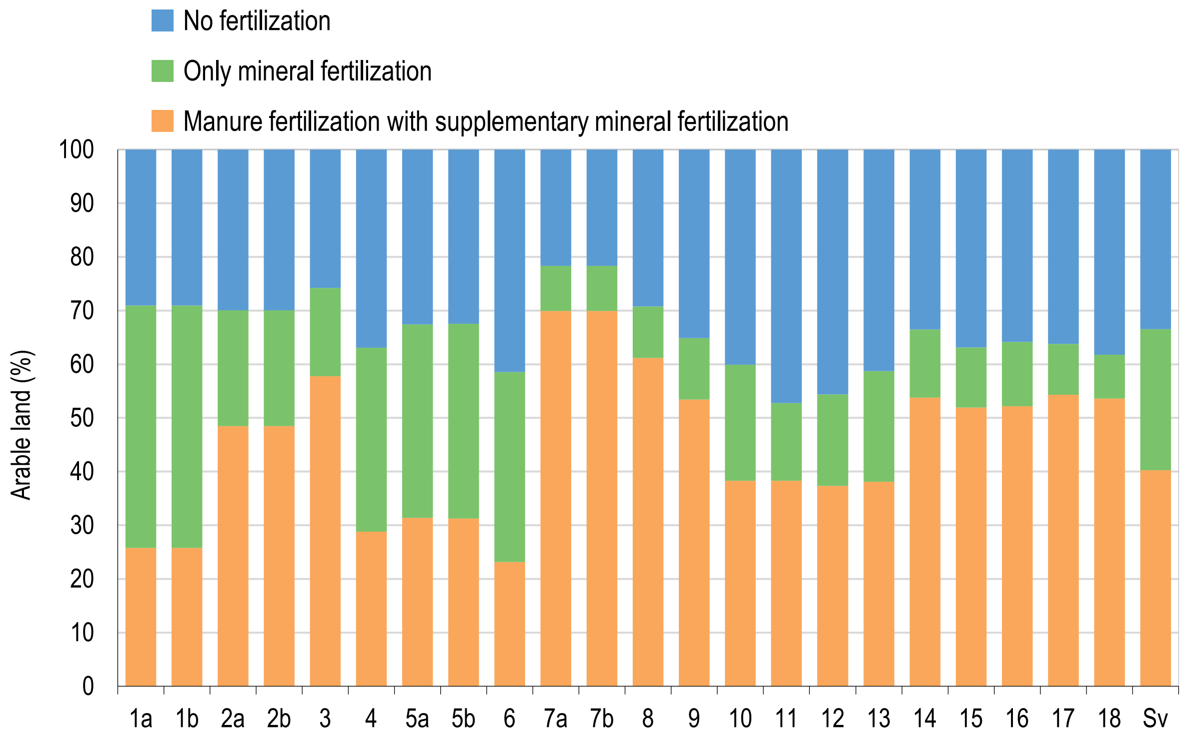

Figure 15. Distribution of the different fertilization regimes for phosphorus in the leakage regions and Sweden (Sv), reported as averages for all crops.

Dates of tillage, sowing and harvest

The dates of tillage were based on statistics from Statistics Sweden from the survey on cultivation measures in agriculture 2012 (SCB, 2013a). Statistics on crop sowing dates are missing and these have therefore been adapted to the tillage dates. The harvest dates have been partly based on statistics on the time of field ripened (cereals and oilseeds) and partly based on information from farming advisory services (potatoes, maize, grassland) or the dates of tillage (sugar beet). Grass ley was harvested twice per year.

Catch crop and spring tillage

The area of catch crops and spring tillage receiving subsidies for 2013 were compiled for production areas (PO18) from the Swedish Board of Agriculture's database for the environmental subsidy "reduced nitrogen leakage" ("Minskat kväveläckage") in the Rural Development Programme. In the calculations, catch crops could occur after all cereal crops, oilseeds and maize (Table 2).

Approximately 5 % of the calculated area had catch crops and/or spring tillage receiving subsidies in 2013 (Figure 16). Roughly, an equal area was tilled in spring without subsidy. The dates for breaking the catch crops in autumn were calculated on the basis of statistical data from the survey on cultivation measures in agriculture 2012 (SCB, 2013a). In the nitrogen leakage calculations, the size of the uptake of nitrogen in catch crop and weeds has been determined by the length of the uptake period, that is, the time between the harvest of the main crop and the end of the growth period in the autumn. The potential nitrogen uptake was about 40-60 kg N/ha if the catch crop grew until the end of the growing season. Although catch crop is a measure that is primarily aimed to reduce nitrogen leaching, it has also been included in the crop sequences for the phosphorus calculations as it is also believed to have an effect on phosphorus leakage.

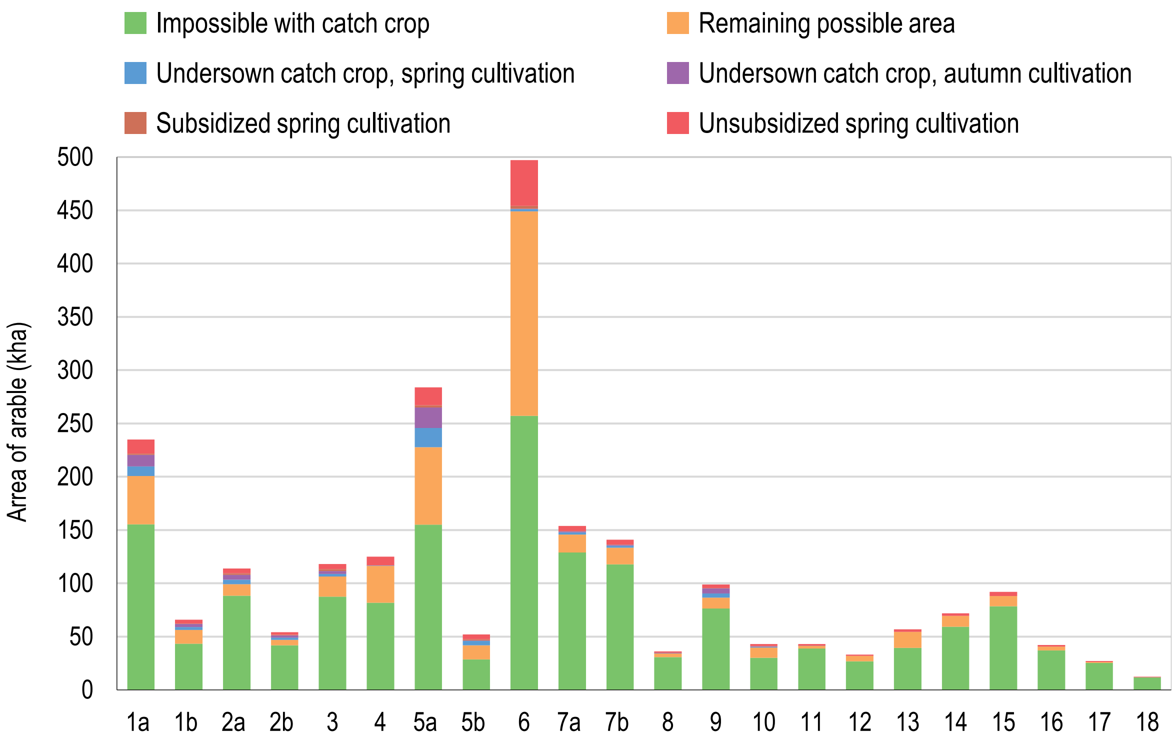

Figure 16. Sown-in catch crop and/or areas with spring tillage and areas where it is assumed to be impossible or possible to have catch crop in 2013. Not all possible area is possible for soil cultivation in spring. Catch crops cannot be followed by grass ley, autumn-sown crops or come after fallow, sugar beet or potatoes. Regions 12-18 were not covered by the subsidiary programme for catch crops and/or spring tillage.

Buffer zones

The area of buffer zones were compiled for production areas (PO18) from the Swedish Board of Agriculture's database for the environmental subsidy "Buffer zones" ("skyddszoner") in the Rural Development Programme. The buffer zone effect was included in the phosphorus leakage equations as follows: two calculations were carried out with NLeCCS where one calculation lacked a buffer zone on the arable land and where the other calculation had a buffer zone included on the arable land.

Subsequently, the results of the two simulations were weighted together in relation to their relative areal coverage in 2013 (Figure 17). In 2013, the total buffer zone area in Sweden was 11,198 ha. The width of the buffer zones was set to the median value for the whole of Sweden (14m), calculated based on data of the area of the buffer zones and corresponding areas for the entire fields (where these were located) from the Swedish Board of Agriculture's database for the environmental subsidy.

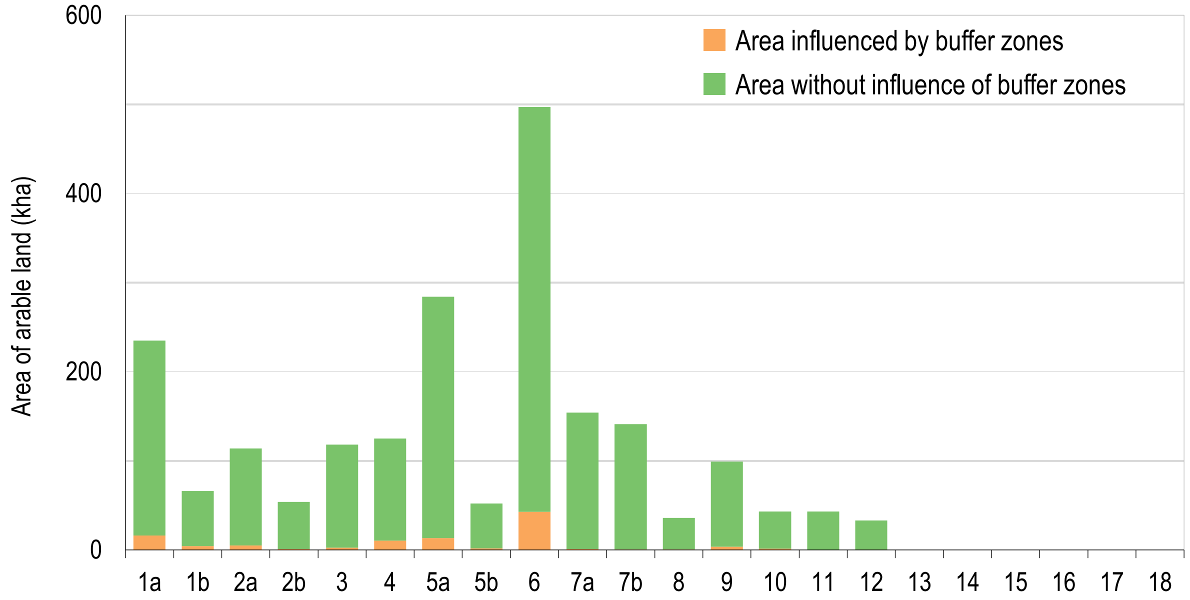

Figure 17. Arable land area with and without influence of buffer zone for the leakage regions (leakage regions 13 - 18 were not covered by buffer zone subsidies).

The impact area is the arable land area that is protected upstream a buffer zone. In the calculations, it has been assumed that if a field has a buffer zone on any part of the field, the entire field is affected. The calculation of the impact area was made by calculating the stream length for all arable land and for the part of the arable land that had a buffer zone and then calculating the percentage of arable land having a buffer zone. In this lies an assumption that all the arable land we calculate is adjacent to a stream or an open ditch that connects to a stream. The buffer zone was not included in the calculation of the standard leakage rates for nitrogen (a buffer zone, however, affects area use/crop distribution and therefore has an effect on nitrogen leakage in connection with load calculations since the nitrogen leakage rates from the buffer zone area has been assumed to be the same as for the leakage rate from extensive grassland).

Crop yields

Harvests yields vary greatly between individual years. When calculating the standard leakage with NLeCCS, we have therefore chosen to use normalized values for harvest yields, so-called standard harvest yields (The Swedish Board of Agriculture and Statistics Sweden) as inputs. These standard values change slightly from year to year depending on long-term changes in cultivation (e.g. changed farming methods, new crop varieties, new fertilization strategies). SOILNDB and ICECREAMDB simulate the actual crop yield based on potential harvest yields specified as input to the models. As a basis for setting this potential harvest yield, the standard harvest yield for each crop and region has been used as a "target yield" for the simulated harvest. For the calculations of the standard leakage in 2013, statistical data from Statistics Sweden on standard yields in 2013 (Jordbruksverket och SCB, 2013) were used to estimate the target yields for all crops except grass ley and maize (for grass ley and maize, multi-year averages were used).

In the nitrogen calculation, adjusted target yields (10-25% depending on the crop) were used as values for the potential yields in the simulations. The simulated nitrogen yields for the crops were allowed to vary so that for individual years in the crop sequences they exceeded the nitrogen target yields (the target harvest multiplied by the nitrogen content of the harvest product) and in other years they were below the target yield, with the aim that the simulated yields on average for the crop sequences would correspond to the target yields. Data on harvests and fertilizations were collected from the same regional level. Statistical data on the standard yields for a given crop refer to all areas with this crop regardless of the type and level of fertilization it received. By using Statistics Sweden's co-processing of the harvest and fertilizer surveys (Bergström et al., 2009 and SCB, 2013b), representative target harvest yields for cereal crops (excluding maize) and oilseeds could be calculated for the two different fertilization regimes (Figure 18). The criterion for the calculations has been that the ratio between the simulated nitrogen harvest and the nitrogen target harvest should be 1.00 on average for all crops excluding grass ley and fallow, in the different leakage regions. In order to meet the ratio criteria, the nitrogen content of the harvest products has been adjusted. Nitrogen uptake for stubble fallow and green fallow has been calculated using an assumed potential daily uptake during the growing period.

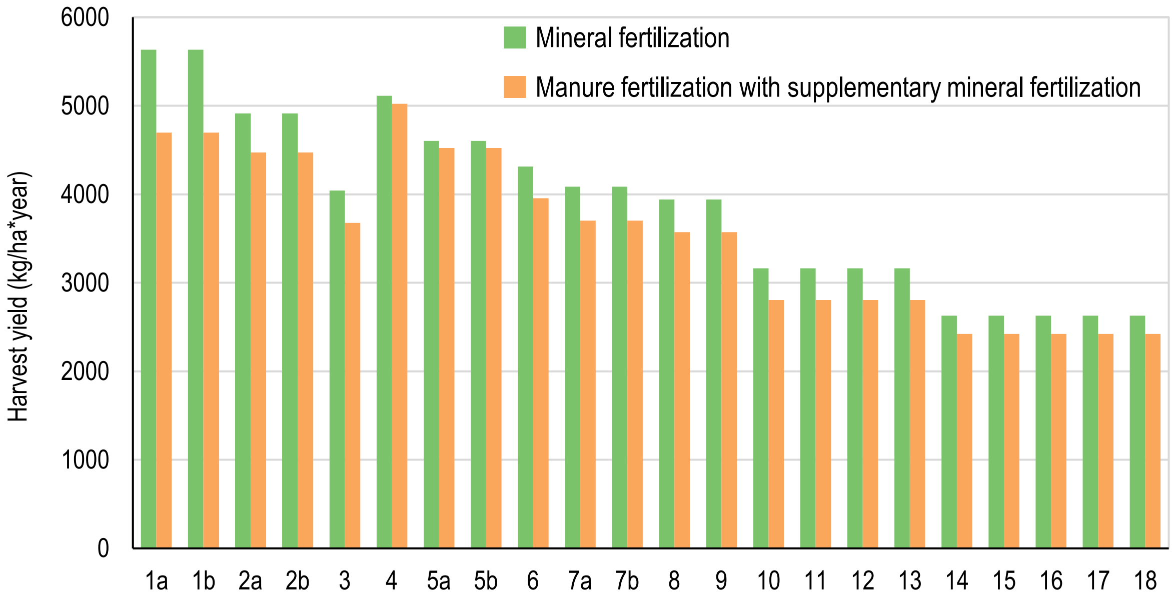

Figure 18. Target yields used in the nitrogen calculation for **spring barley** for the fertilization regimes *only mineral fertilization* and *manure fertilization with supplementary mineral fertilization* in 2013.

In the phosphorus calculation, simulated harvest yield of both biomass and phosphorus was calibrated to correspond to the target harvest yield for each crop and leakage region. For phosphorus, there is not as strong a link between phosphorus fertilization and harvest levels as it is in the case of nitrogen. Due to the weaker link, the target harvest yields for the phosphorus calculation have been selected according to the best possible regional resolution of statistical data, i.e. no synchronization has been made against the regional level at which the fertilization data came from. If data for standard harvests for PO18 existed, these have been used in the first place (then in descending order PO8, RO and finally National).

Extensive grassland/Background

As background leakage in the PLC6 load calculations, leakage from extensive grassland was used. This is defined as a permanent grass vegetation that is not fertilized or harvested. Extensive grassland has not been included in the crop sequences as described above, but has been calculated separately for all combinations of soil and leakage region as monoculture for a 30-year period for which annual averages have been calculated.

For the nitrogen calculation, the daily potential uptake of nitrogen to the plant was assumed to exceed the available mineral nitrogen in the soil for the actual simulated nitrogen uptake for most of the growing season, that is, the vegetation has been assumed to take up the nitrogen available via mineralization and deposition, etc. However, during the beginning and especially the end of the growing season, the potential uptake was assumed to be lower than the available nitrogen for uptake. Similar to the calculation of the standard leakage for arable land in 2013, the organic pool of the soil has been assumed to be in balance in all leakage regions when calculating nitrogen leakage for extensive grassland. In order to obtain balance in the soil's organic N-pool in the simulations, the mineralization of organic nitrogen (humus-N) in the soils has therefore been adapted for the different leakage regions.

For the phosphorus calculation, the plant uptake of phosphorus in the extensive grassland has been assumed to correspond to approximately 2/3 of a normal grass ley. Furthermore, it was assumed that all above ground biomass died during the winters and was incorporated into the organic pool of the soil. Measured values of the phosphorus content from the subsoil (Djodjic & Orback, 2013) have been used for the phosphorus content of the topsoil in the calculation of extensive grassland for background leakage to disregard the increase in topsoil phosphorus that has taken place due to storage fertilization (Andersson et al., 2000).

Examples of estimated standard leakage

Below are some examples of calculated standard leakage rates for 2013 and factors affecting their size. For a more complete description of the results see Johnsson et al (2016).

Nitrogen leakage

Influence of region, crop and soil

Differences in the size of the calculated standard leakage of nitrogen between the different leakage regions depend on several factors; crop cultivation practices are different for the different leakage regions, the climate is different (precipitation, temperature and length of growing season, etc.) and in addition, the nitrogen deposition varies between the leakage regions (Figure 19). The influence of soil type on nitrogen leakage is significant. The calculations for 2013 show a clear link between increased nitrogen leakage and decreasing clay content in the soil (Figure 20).

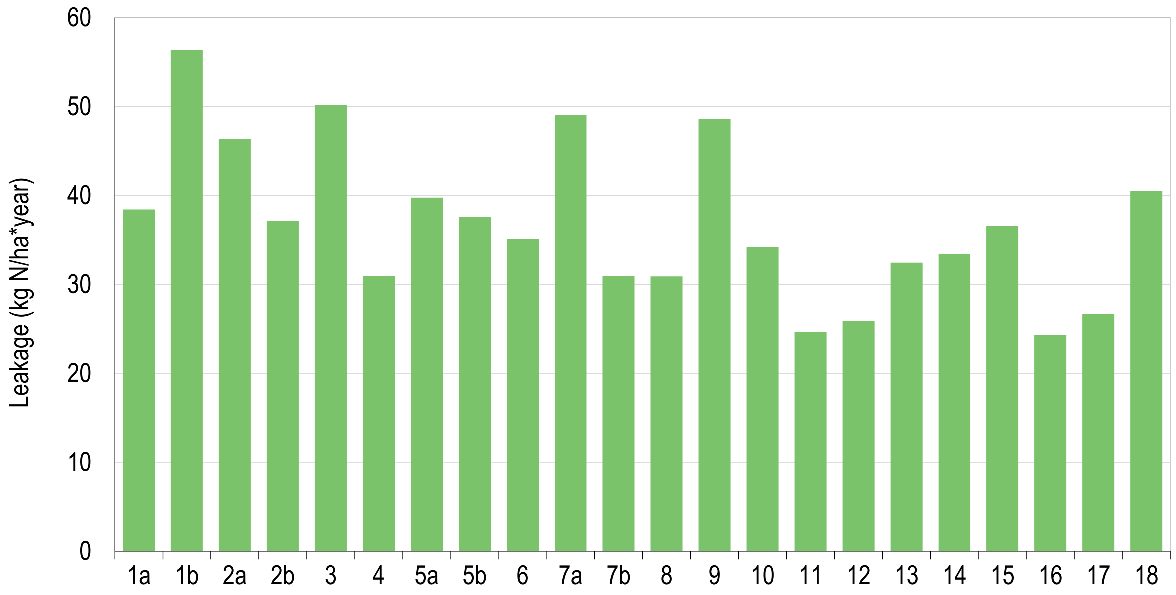

Figure 19. Example of effect of region: Normal leakage of nitrogen in 2013 for **spring barley** on **sandy loam** in the leakage regions.

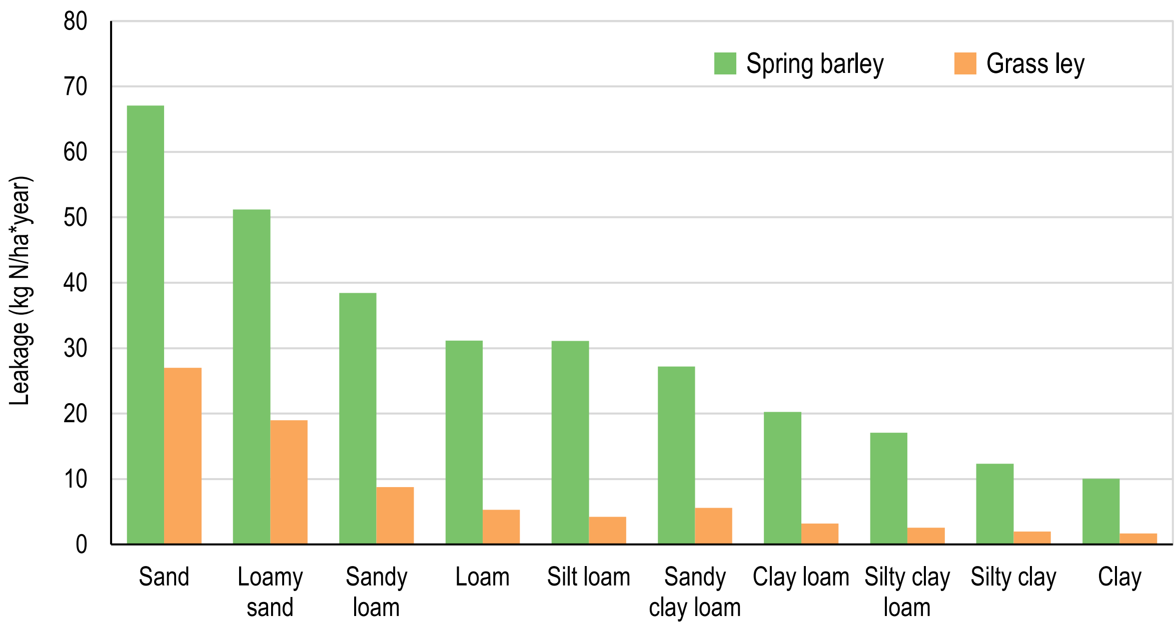

Figure 20. Examples of the effect of soil type: Standard leakage of nitrogen in 2013 for the crops spring barley and grass ley in leakage region 1a for all soil types.

When comparing the standard leakage of nitrogen between different crops, the length of the growing season is of great importance. The largest crop differences occurred between perennial grass ley and annual crops that have a shorter growing season than grass ley (Figure 21). High leakage from potatoes was due to a short growing season and large amounts of easily degradable nitrogen that was plowed under. The nitrogen leakage of a particular crop also depends to a large extent on which crop follows in the plant sequence and the amount of nitrogen uptake of that crop (see below under "influence of crop combinations").

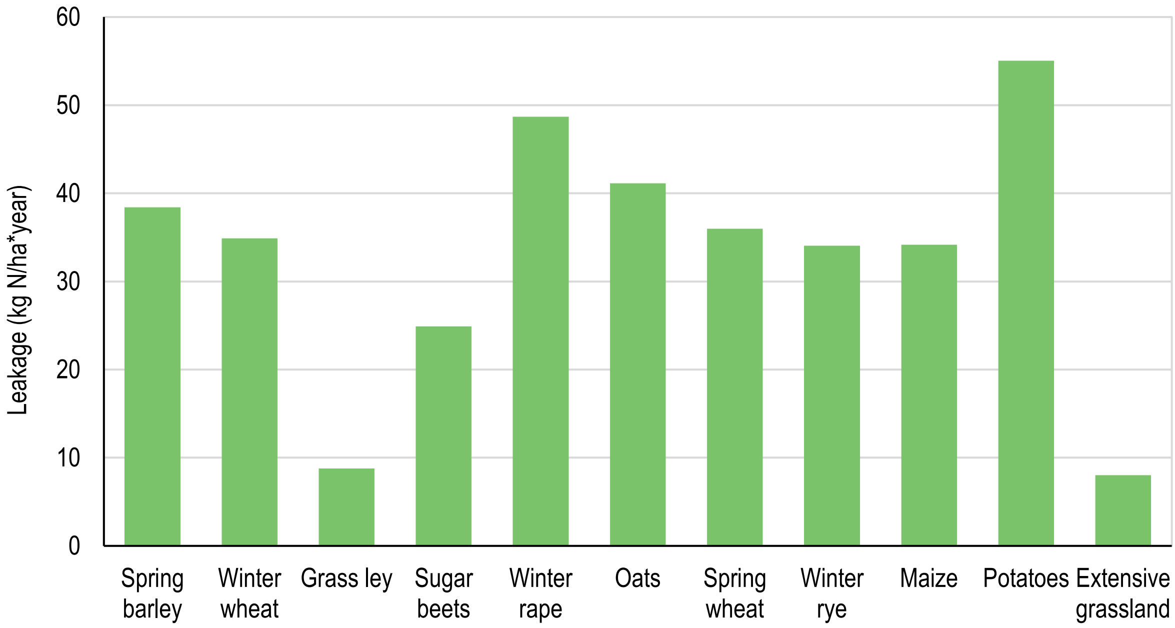

Figure 21. Examples of crop effect: Standard leakage of nitrogen in 2013 for all crops in leakage region **1a**, soil type **sandy loam**.

Taking into account the composition of soil types and the crop distribution that existed in the different regions, the calculations for 2013 showed that standard leakage was greatest in the southwestern part of the country and lower in the eastern and northern parts of the country (Figure 22). The high leakage in Western Sweden was mainly due to high runoff and a high proportion of light soils, i.e. soils with a low clay content. Low leakage rates in northern Sweden was largely due to a high proportion of grass leys.

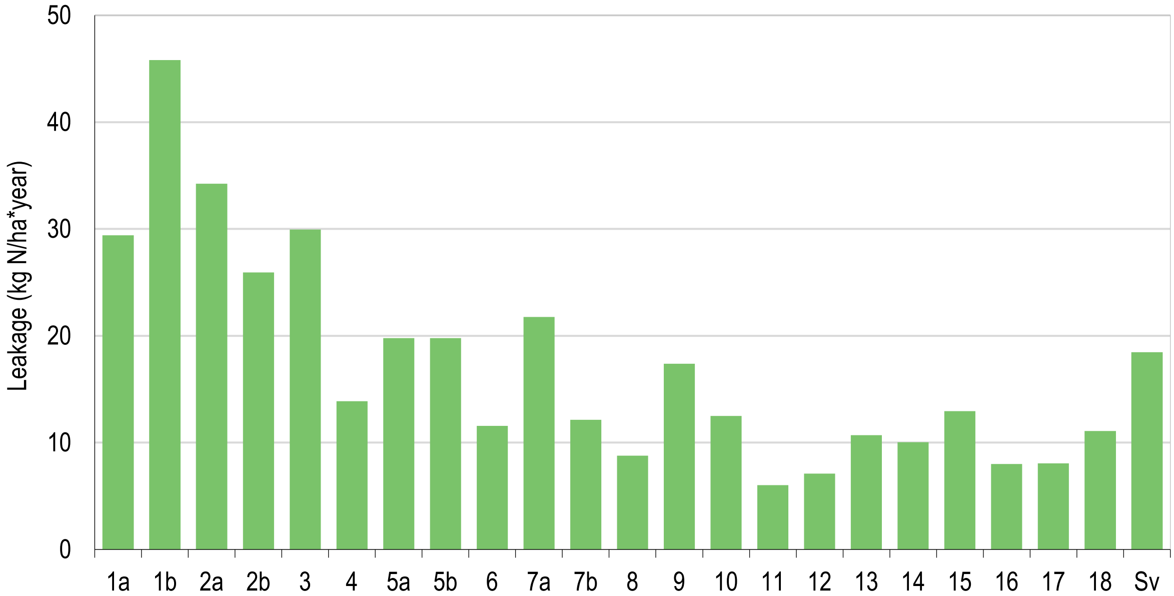

Figure 22. Area-weighted averages with respect to soil types and crop distribution for standard nitrogen leakage in 2013, for calculated area in all leakage regions and for the whole of Sweden (Sv).

Influence of crop combinations and cultivation measures

Effect of crop rotation, catch crop and tillage date

The mixture of crops in a leakage region determines the crop rotations that occur and to what extent they are in a region. Different subsequent crops following a crop have different impact because the subsequent crop determines, for example, the time of tillage, the start of the next uptake period and the size of the uptake. For example, if spring barley is followed by spring barley, a nutrient uptake by weeds starts after harvest, which lasts until a relatively late tillage. If spring barley is followed instead by an autumn-sown crop, such as winter wheat, nutrient uptake by weeds will not be as long-lasting because tillage and sowing of autumn-sown crop occurs relatively soon after the spring barley harvest. The autumn-sown crop then has instead an autumn uptake that lasts until the end of the growing period. All these differences in crop sequences affect the size of nitrogen leakage and in some cases by very much which the calculations for 2013 show. For example, both ley sown into spring barley and catch crop sown into spring barley resulted in a greater nitrogen uptake after harvest than growth of weeds after spring barley harvest did and thus a significantly lower leakage rate (Figure 23).

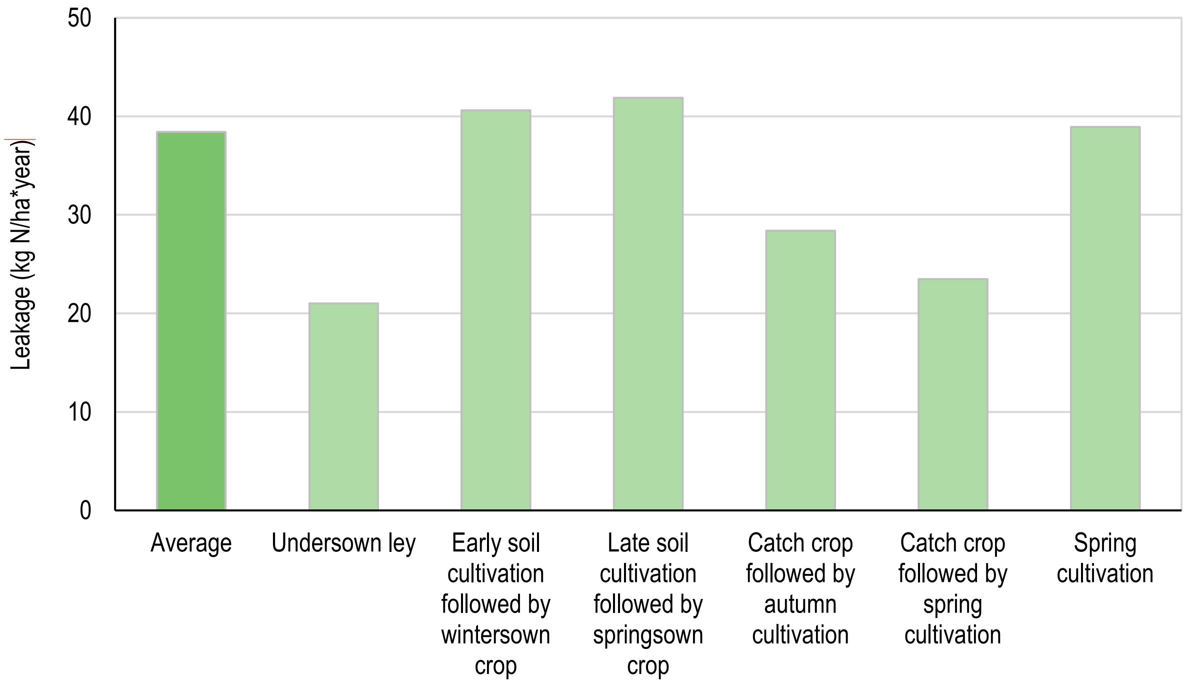

Figure 23. Examples of effect of crop sequences, tillage and catch crop: Standard leakage of nitrogen in 2013 for **spring barley** followed by various crop combinations, tillage dates and catch crops on **sandy loam** in leakage region **1a**.

Grass ley and breaking of the ley

In the crop sequence for the calculation of the standard leakage of nitrogen in 2013, grass leys appeared in sequences of up to five or six years length, of which only the last year was tilled, which affected the size of the nitrogen leakage. For the years where grass ley was followed by grass ley, the leakage was very low while the last year of grass ley (ending with a breaking of the ley) had a significantly higher leakage rate (Figure 24). With an early tillage, that is, when grass ley is followed by autumn sowing, the winter crop was only able to take up a small part of the nitrogen that became available after the breaking of the ley and the leaching could be very high.

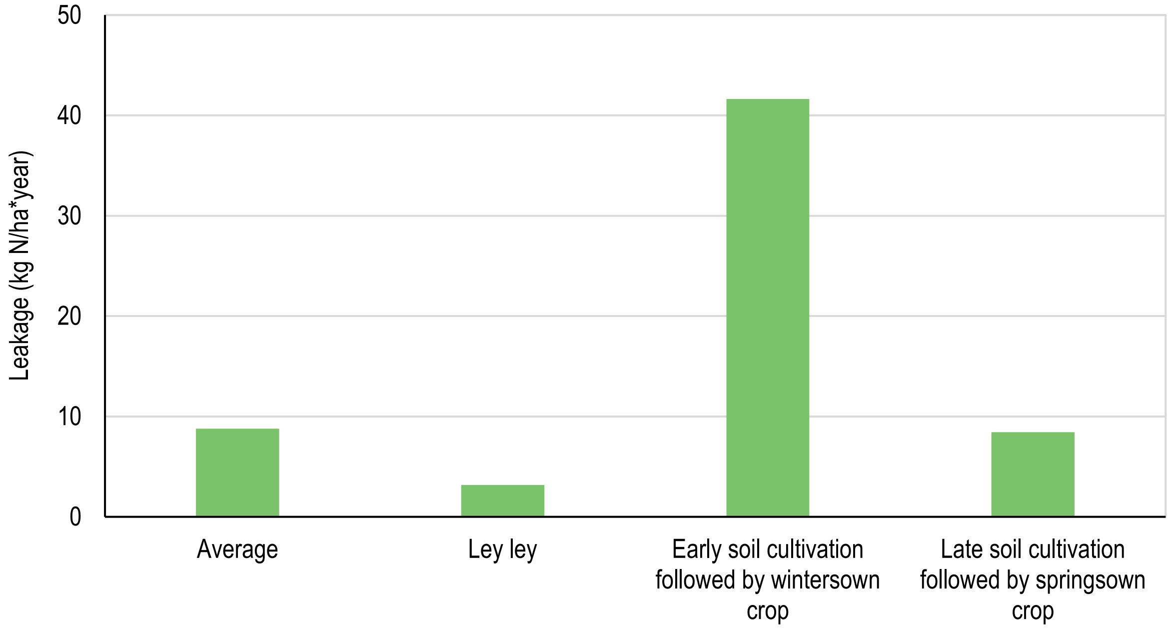

Figure 24. Examples of the effect of grass ley and breaking of grass ley: Standard leakage of rates nitrogen in 2013 for grass ley (average) and grass ley followed by different crops; grass ley followed by grass ley (Ley ley) and grass ley with different tillage dates on **sandy loam** in leakage region **1a**.

Stubble fallow and green fallow

In the calculations for 2013, the fallow consisted of stubble- and green fallow, which were included in the crop sequences, and long-term fallow. Green fallow had lower leakage than the stubble fallow due to a higher plant uptake of mineral nitrogen from the soil (Figure 25). Long-term fallow was not included in the crop sequences but was assumed to have a permanent plant cover with a leakage as a grass ley followed by grass ley that has a significantly lower leakage (see above section "grass ley and breaking of the ley")

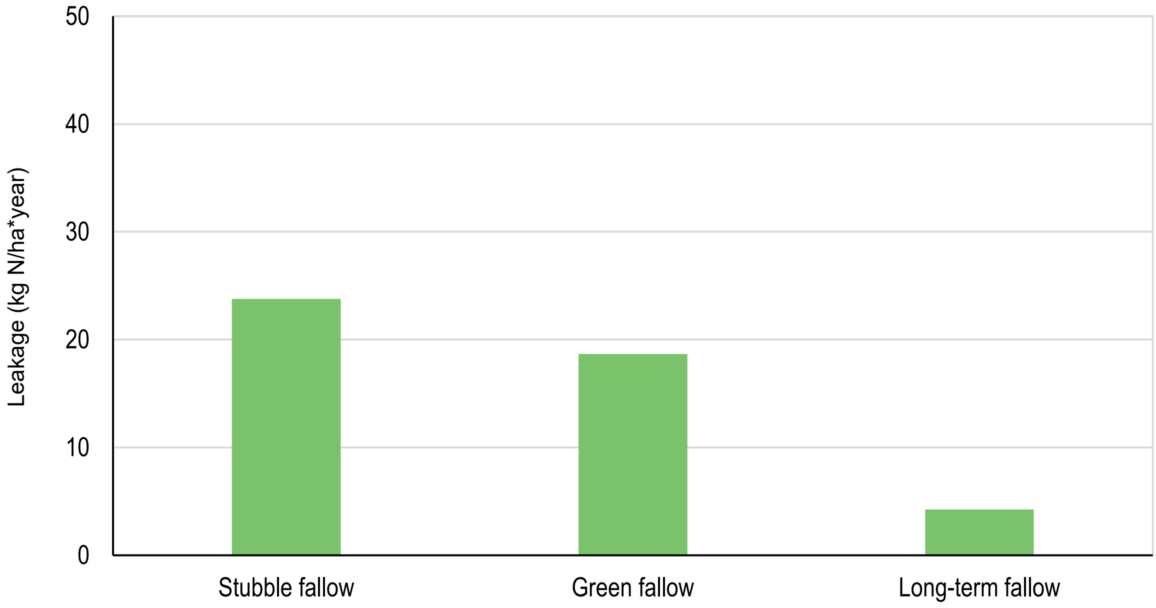

Figure 25. Examples of the effect of different fallows: Normal leakage rates of nitrogen in 2013 for stubble fallow, green fallow and long-term fallow on **sandy loam** in leakage region **6**.

Fertilizer regimes

The main difference between the fertilization regime *manure fertilization with supplementary mineral fertilization* and the fertilization regime *only mineral fertilization* is the supply of organically bound nitrogen in the former. Almost the same amount of mineral nitrogen (nitrate and ammonium) is added in both the fertilization regimes (Figure 26). The added organic nitrogen can contribute to an increased mineralization of nitrogen even during periods when there is no crop that can take up the mineral nitrogen, with increased leaching risk as a result. In addition, some of the manure fertilization takes place in the autumn, which can also contribute to higher leaching (see below section "manure fertilization dates"). In the calculation for 2013, the standard leakage of nitrogen from the fertilization regime *manure fertilization with supplementary mineral fertilization* was slightly higher compared to the leakage from the fertilization regime *only mineral fertilization* (Figure 26). A greater amount of nitrogen was added to the fertilizer regime *manure fertilization with supplementary mineral fertilization* compared to the fertilization regime *only mineral fertilization* without the corresponding harvests being larger.

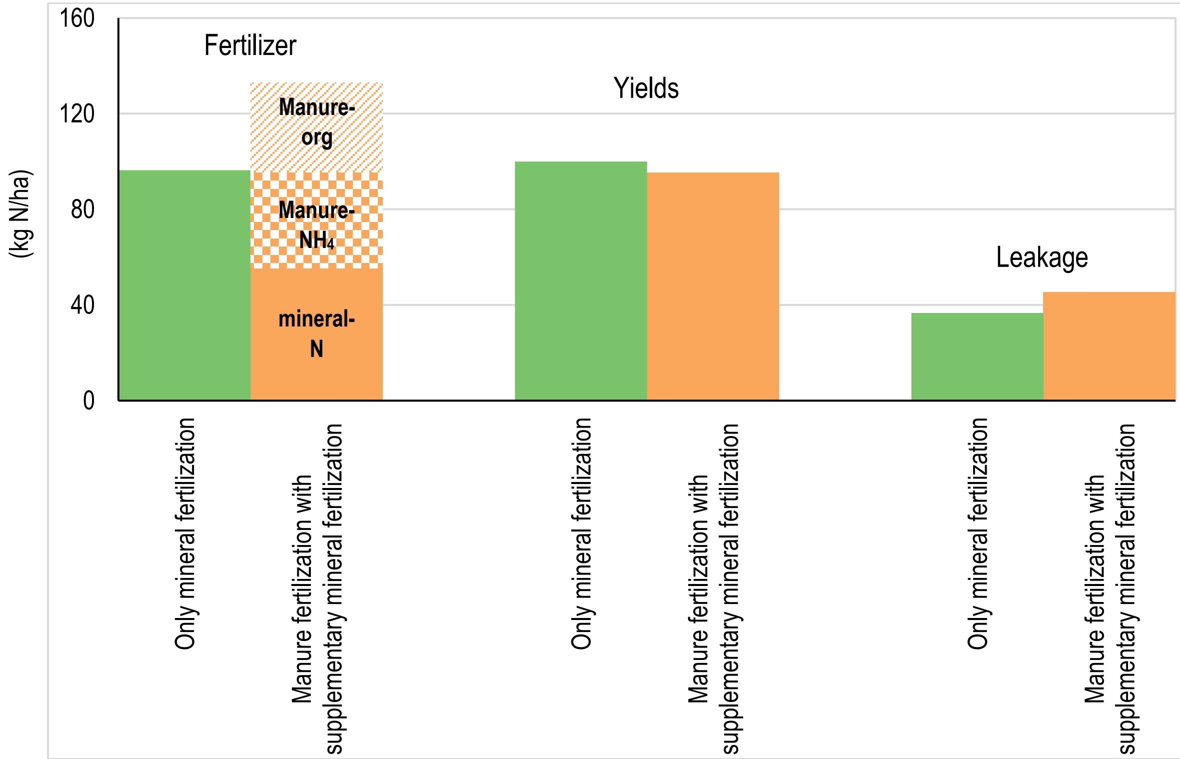

Figure 26. Examples of the effect of fertilization regimes: Nitrogen fertilization, nitrogen yields and Standard leakage rates of nitrogen in 2013 for **spring barley** for the two fertilization regimens *only mineral fertilization* and *manure fertilization with supplementary mineral fertilization* on **sandy loam** in leakage region **1a**. Manure-org refers to the organic part of the nitrogen content of the manure, Manure-NH4 refers to the immediate plant-accessible part of the nitrogen content of the manure and mineral-N the complementary mineral nitrogen fertilizer.

Manure application time

The size of the nitrogen leakage is affected by whether the manure is applied in the fall or spring. In the case of autumn applied manure, there is a risk that the mineral nitrogen found in the manure is leached during the winter if no plant uptake occurs. For example, in the standard leakage calculation for 2013, the leaching of nitrogen in leakage region 5a was higher when the manure was applied in autumn compared to when it was applied in spring for barley and grass ley (Figure 27).

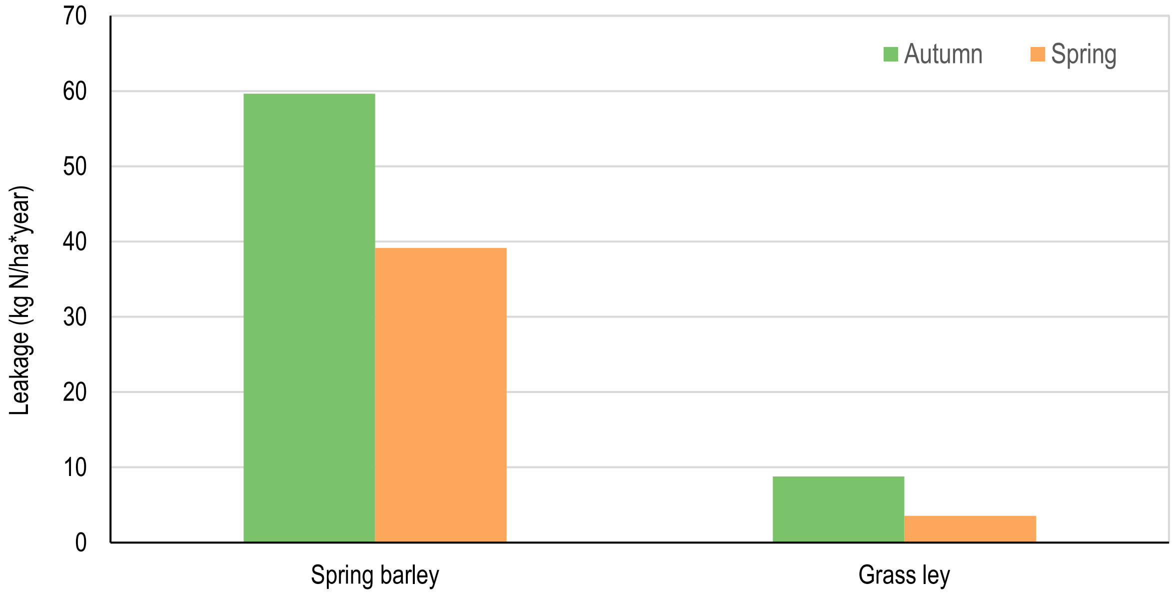

Figure 27. Example of the effect of the time point for manure application: Standard leakage of nitrogen in 2013 for spring barley and grass ley for the fertilization regime *manure fertilization with supplementary mineral fertilization* for different time points for application on **sandy loam** in leakage region **5a**. Leaching summarized for the agrohydrologic year (July 1 year 1 – June 30 year 2) when manure was spread, i.e. the agrohydrologic year before the agrohydrologic year that is usually reported for the standard leaching rates.

Phosphorus leakage

Influence of region, soil type, slope and soil phosphorus content

As with nitrogen, there are many factors that affect how large the standard leakage of phosphorus will be from a region. In particular, precipitation and discharge conditions are of great importance for phosphorus. This was evident in the leakage calculation for 2013 where regions with high rainfall and discharge, such as regions 1b, 7a, 11 and 18, had high phosphorus losses (Figure 28). In northern regions with a lot of snow, heavy flows during snowmelt can also cause high losses.

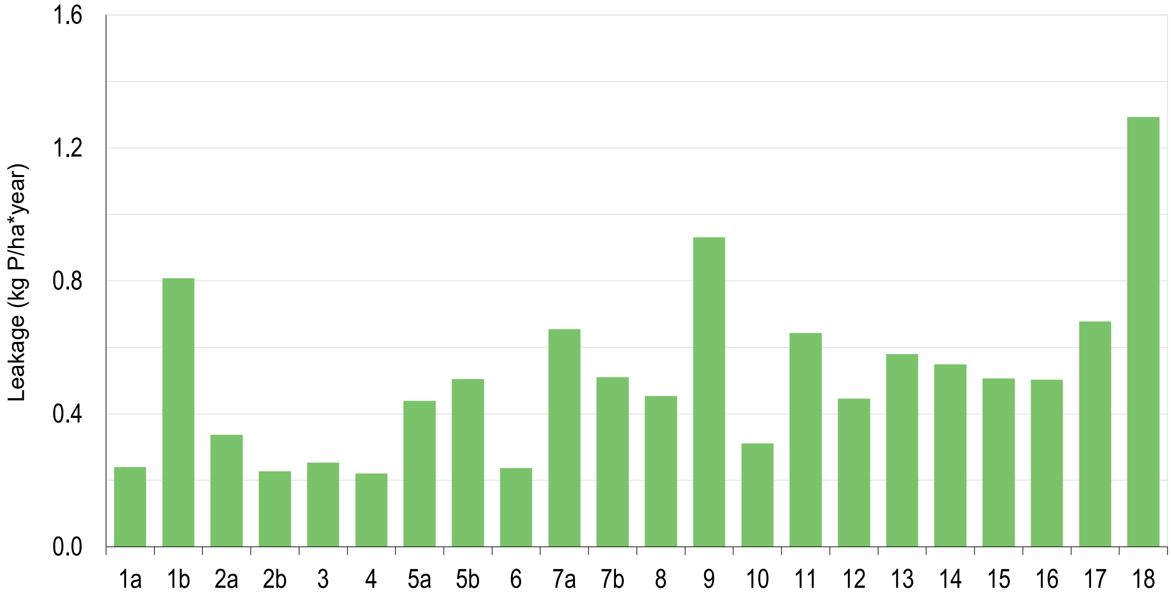

Figure 28. Examples of the effect of leakage region: Standard leakage of phosphorus in 2013 for **spring barley** for the soil **loam** in all leakage regions. For all regions in this figure, both slope and soil phosphorus level have been set to the Sweden medium (3.7% and 71 mg P/100g respectively), in order to here only demonstrate differences due to climate and cultivation measures.

The soil type is also of great importance for the calculated phosphorus leakage (Figure 29). The most significant property of the soils is how easily they release sediment and thus particular P, if there are macropores and if surface water is often formed. In silty and clayey soils, sediment and particular P are both released and transported to a greater extent than in the more coarse-grained soils.

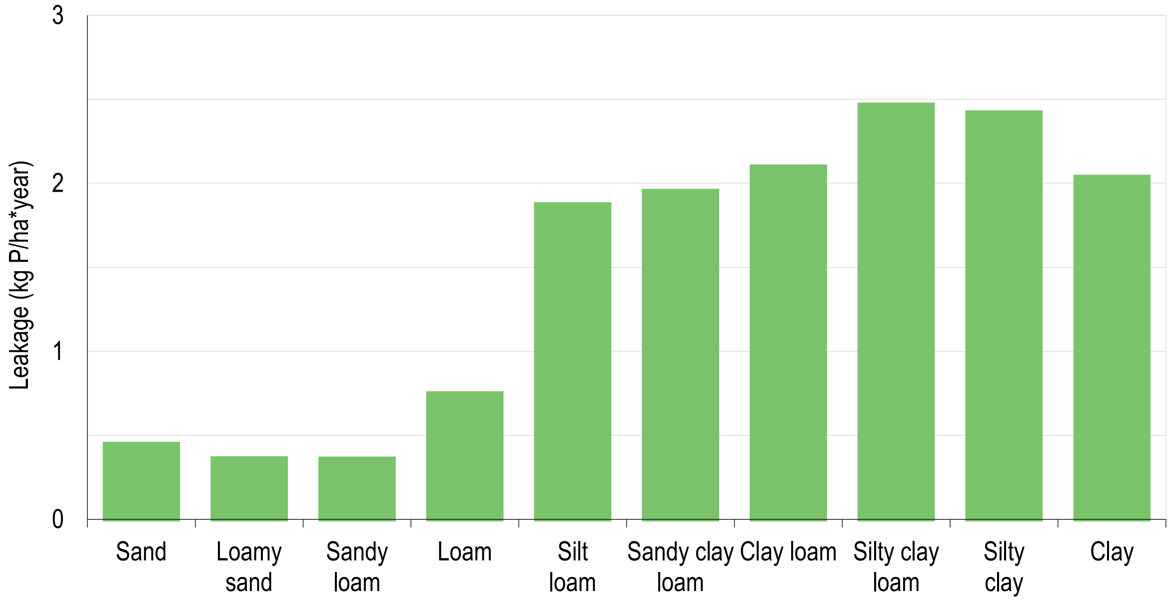

Figure 29. Example of soil type effect: Standard phosphorus leakage in 2013 for **spring barley** in leakage region **1b** for the different soils.

Other determining factors for the size of the phosphorus leakage are the slope of the field and soil phosphorus content. An increase in slope primarily increases the risk of erosion losses and thus losses of particular P in surface runoff (Figure 30a). Higher soil phosphorus content results in higher P concentration of the sediments lost from the fields as well as more dissolved P in discharge water (Figure 30b).

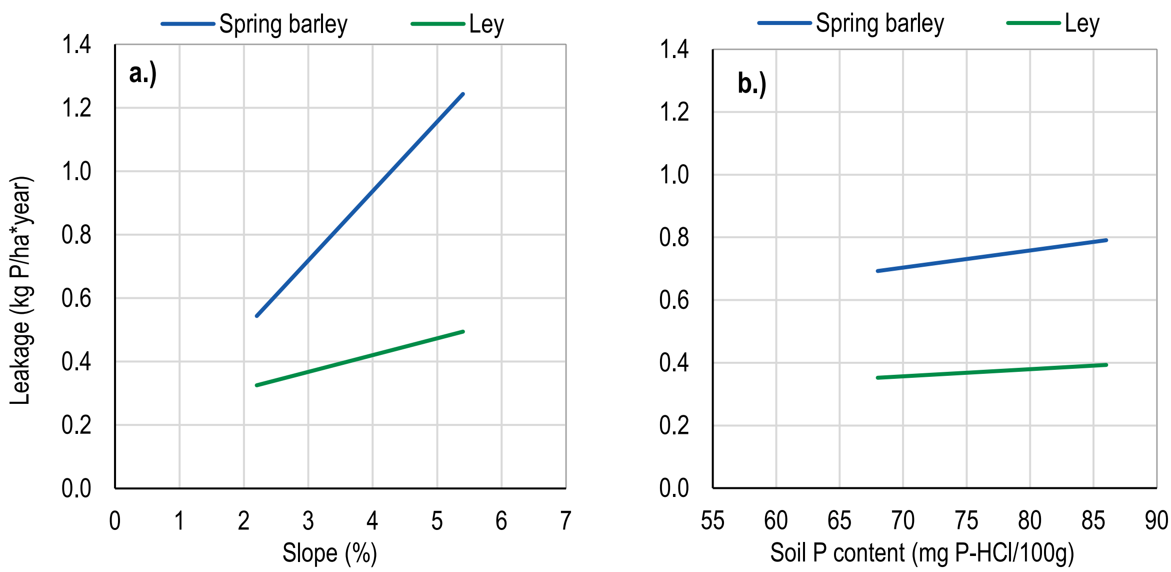

Figure 30. Examples of the effect of slope and soil phosphorus content: Standard leakage of phosphorus in 2013 (dissolved + particulate) depending on the slope of the soil (a) and soil phosphorus content (b) shown for spring barley and grass ley in leakage region **1b** for the soil type **Loam**. The end points of the lines are the 10th and 90th percentiles respectively of the values for slope/soil phosphorus in the region.

The influence of the different crops on the calculated phosphorus losses is largely determined by how they affect surface run-off and how they protect the soil surface in heavy rains (Figure 31). For spring-sown crops, the soil can be left bare for a large part of the year and the soil surface is thus exposed to rain and heavy runoffs. Autumn-sown crops cover the ground for a larger part of the year compared to spring-sown crops, but are still sparse during winter and spring. The best protective effect has grass leys that with its perennial plant cover has high transpiration that dries out the soil as well as provides good protection for the soil surface in case of rain and surface runoff. For the grass leys, however, we have not taken into account that freezing/thaw related release of phosphorus can take place from growing crops during the winter, which may result in that the losses from, for example, grass leys may be partially underestimated. Calculated phosphorus losses from extensive grassland, i.e. fields with a permanent grass cover, not being harvested or fertilized, are used as a measure of background losses from agricultural land. The low losses from extensive grassland is partly due to the fact that it has a perennial plant cover just like for regular grassland, but also because the soil phosphorus content is lower because there is no fertilization. Maize and potatoes stand out as high-leaking crops in the calculations, especially in terms of the loss of particular P.

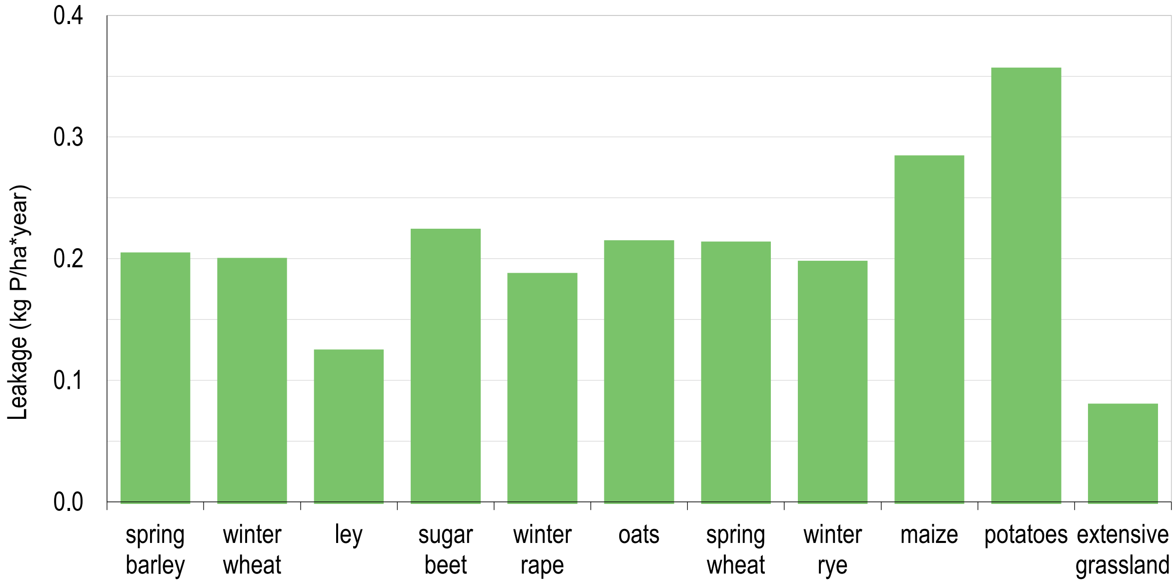

Figure 31. Examples of crop effect: Standard phosphorus leakage in 2013 from leakage region **1a** for all calculated crops on **loam**, shown for medium slope and medium soil phosphorus content.

The weighted effect of different soils and crops and their influence on runoff, flow paths (surface runoff, macropore and micropore flow) and phosphorus forms (dissolved and particulate) is very complex (Figure 32). Unlike nitrogen, the northernmost leakage regions with heavy spring floods have relatively high losses, despite less intensive agriculture.

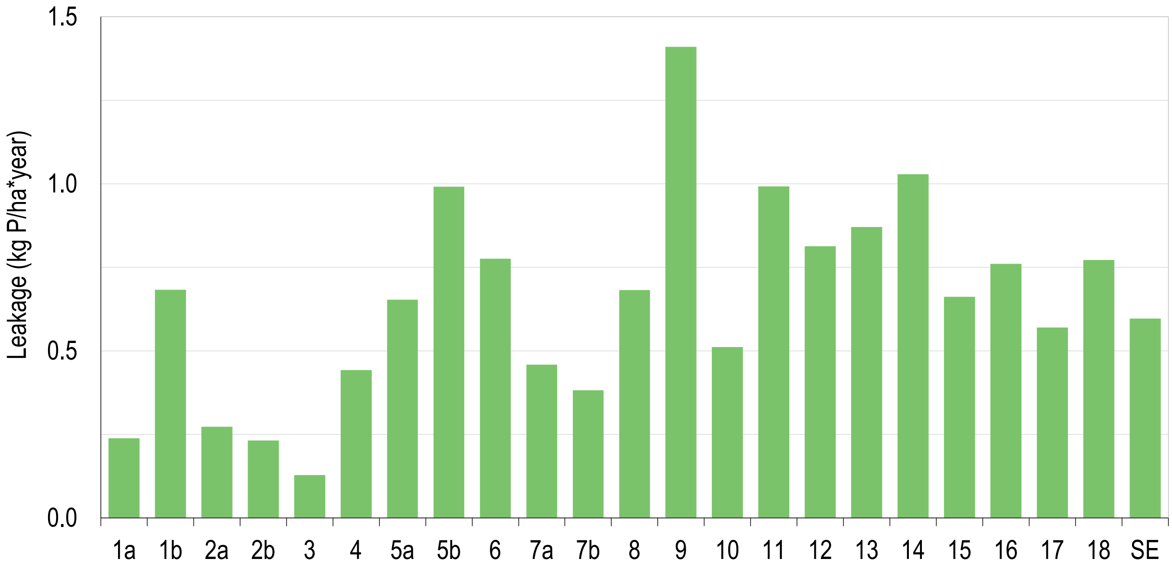

Figure 32. Area-weighted averages with regard to soil and crop distribution for the standard leakage of phosphorus in 2013, for calculated area in leakage regions and in whole Sweden (Sv).

Leakage pathways

Soil type, crops, precipitation and runoff dynamics are thus decisive for the transport pathways through which phosphorus will be lost as well as for what forms of phosphorus will be lost (Figure 33). Both transport via surface runoff and through macropores is episodic and occurs only when precipitation exceeds the infiltration capacity of the soil, while transport via the finer pore system of the soil occurs more continuously with percolating water. When the losses occur via macropore flow, the concentrations are more dependent on the soil's content of phosphorus in the topsoil, partly because no adsorption of dissolved P takes place in deeper soil layers when transported in macropores and partly because particulate P formed in the topsoil will be transported directly to drains by macropore flow.

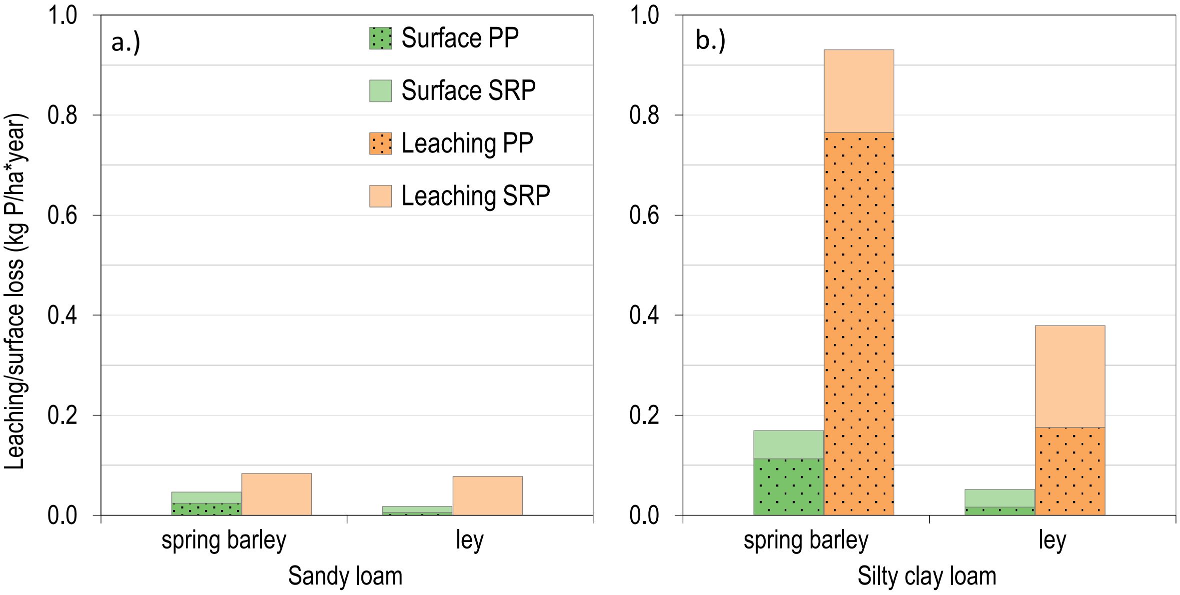

Figure 33. Examples of the effect of leakage pathways (surface/infiltration) /fractions (SRP/PP): Standard leakage of phosphorus in 2013 split into losses via surface runoff (surface) and losses through the soil via leaching (SRP = dissolved phosphorus, PP = particulate phosphorus) for spring barley and grass ley in leakage region **6** for the sandy loam (a) and silty clay loam (b). Shown for medium slope and medium soil phosphorus content for each leakage region.

Buffer zones

Buffer zones have a significant effect on the calculated leakage of phosphorus. The buffer zone effect depends primarily on the soil type, the slope of the field and the crop grown on the field together with the precipitation pattern. On coarser soils (sand, loamy sand and sandy loam) with high hydraulic conductivity, surface runoff rarely occurs and the surface losses of phosphorus are small (Figure 34). On heavier clay soils (silty clay loam, silty clay and clay) on the other hand, surface water is more often formed and the losses with surface runoff are also high. On the soils with the largest surface losses, the protection zone also has the largest effect in reducing P losses. In areas with higher precipitation more surface runoff occur regardless of soil type than in areas with lower precipitation (Figures 34a and b) and therefore the buffer zones will reduce losses more in precipitation-rich areas. In the calculation of standard leakage for 2013, buffer zones reduced the surface losses of phosphorus from fields by between 30 and 40% in areas with lower runoff (Figure 34a) and by between 30 and 55% in areas with high runoff (Figure 34b).

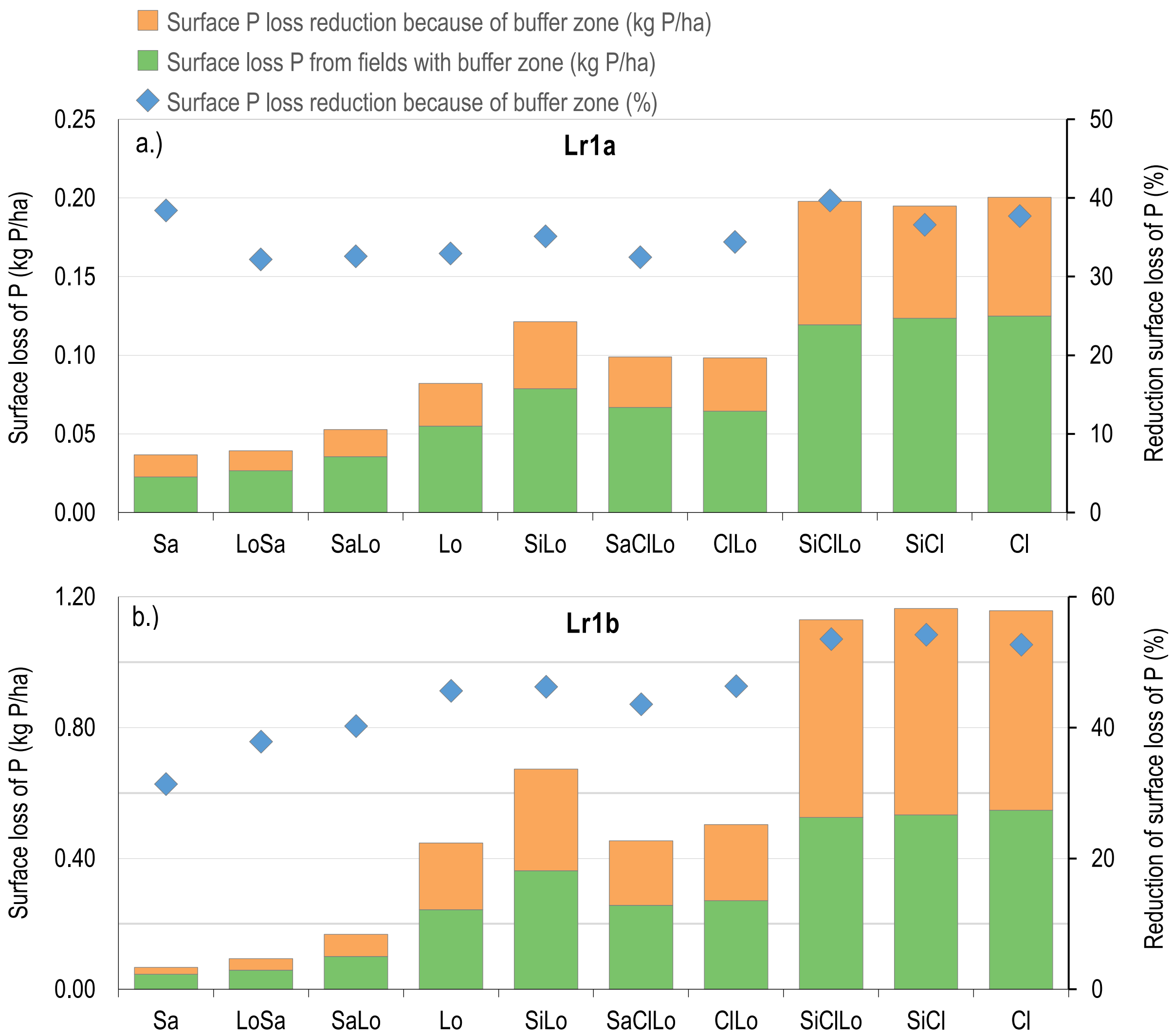

Figure 34. Example of the effect of a buffer zone: Part of the standard leakage of phosphorus in 2013 lost via surface runoff (SRP+PP) for the different soils in leakage region **1a** (a) and leakage region **1b** (b) shown for **spring barley**. The runoff in region 1a is 256mm and in region 1b 515 mm. The sum of phosphorus surface reduction (orange) and phosphorus surface loss (green) from fields with buffer zone corresponds to the surface losses from a field without buffer zone (i.e. the surface loss part of the standard leakage in 2013). The reduction effect is shown both as kg P/ha (bars) and as a percentage (points). Shown for medium slope and medium soil phosphorus content for each leakage region.

Examples of applications of standard leakage values

Calculation of load on surrounding seas (HELCOM/PLC6)

In the calculations of the nutrient load on the Baltic Sea and the North Sea in 2014 for reporting to HELCOM-PLC6 (Swedish Agency for Marine and Water Management, 2016), the calculated standard leakage of nitrogen and phosphorus was used to calculate the total contribution from agriculture. The leakage coefficients were used together with information about crop distribution, soil types, slope and soil phosphorus contents for sub-catchments in Sweden to calculate the leakage in these areas. Based on these calculations, a detailed picture of the geographical variation in standard leakage in Sweden could be described (Figure 35, Figure 36).

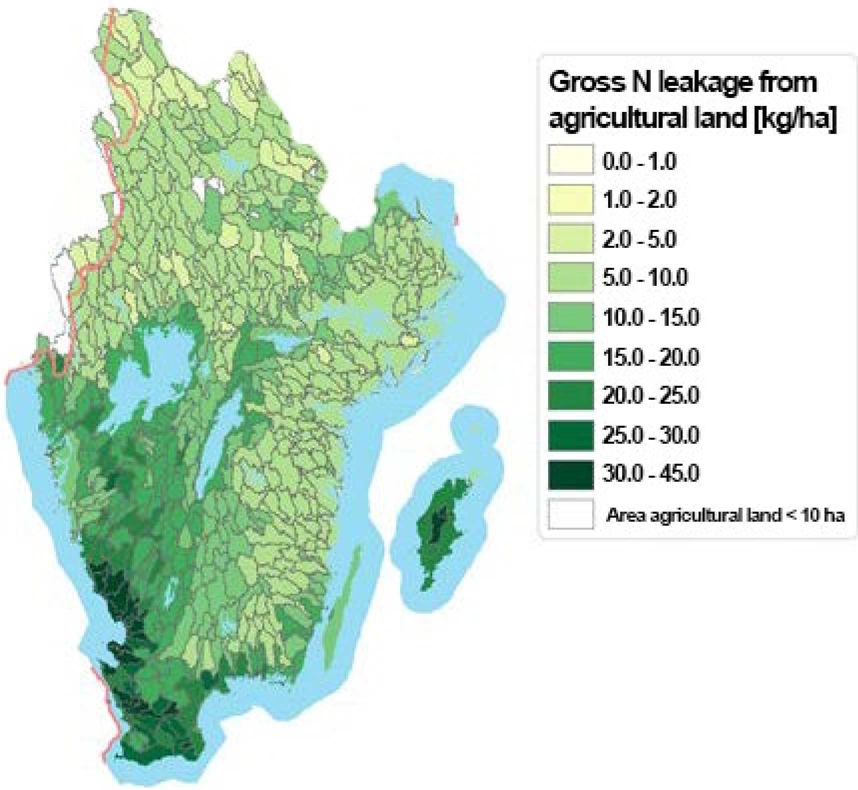

Figure 35. Examples of the use of leakage coefficients: Standard leakage of nitrogen (kg/ha*year) from agricultural land per area of agricultural land when the leakage coefficients are combined with information on soil types and crops in river basins in southern Sweden. Refers to the year 2014 flow normalized for the period 1994-2013. Adapted from the Swedish Agency for Marine & Water Management (2016).

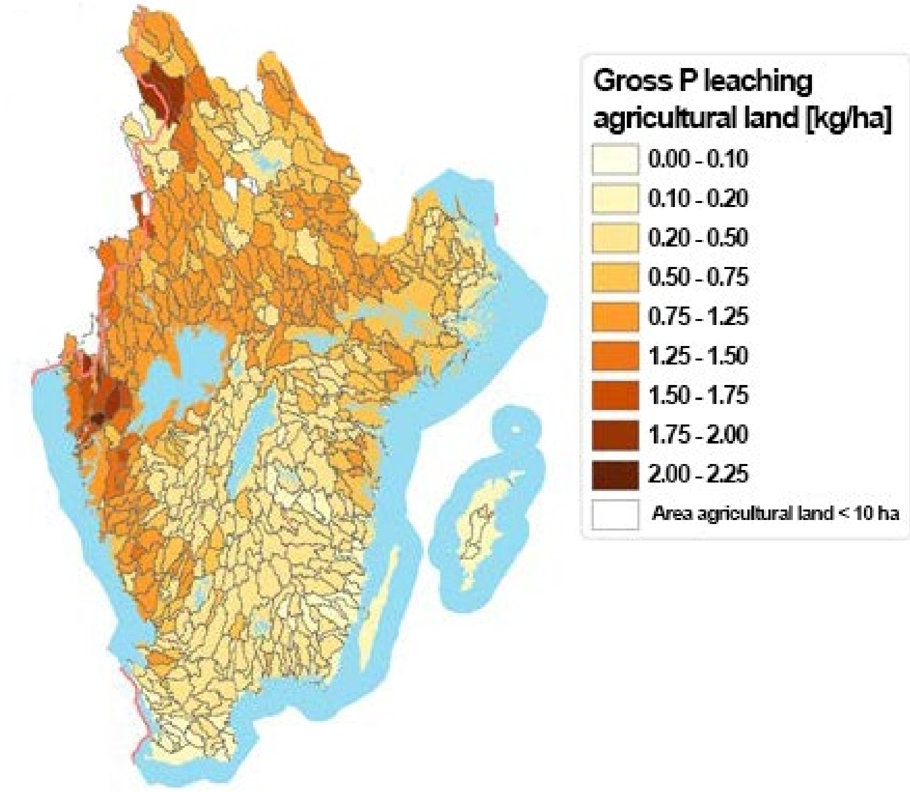

Figure 36. Examples of the use of leakage coefficients: Standard leakage of phosphorus (kg/ha*year) from agricultural land per area of agricultural land when the leakage coefficients are combined with information on soil type, crops, slope and soil phosphorus content in catchments in Sweden. Refers to the year 2014 flow normalized for the period 1994-2013. Adapted from the Swedish Agency for Marine and Water Management (2016).

References

Arheimer, B., Andreasson, J., Fogelberg, S., Johnsson, H., Pers, C., & Persson K. 2005. Climate change impact on water quality: Model results from southern Sweden. *Ambio 34:559-566.*

Andersson, A., Eriksson, J. & Mattson, L., 2000. Phosphorus accumulation in Swedish agricultural soils. *Naturvårdsverket rapport 5110*, Stockholm

Bergström, J., Brånvall G., Andrist Rangel Y. & Svensson J. 2009. Aspects of the Swedish survey on use of fertiliser and animal manure. Regions and Environmental Department & Process Department, Statistics Sweden.

Blombäck, K. & Persson, K. 2009. Utveckling av mer platsberoende parametrisering av ICECREAMDB. *SMED Rapport Nr 33 2009*.

Blombäck, K., Johnsson, H., Lindsjö, A., Mårtensson, K., Persson, K.;& Schmieder F. 2011. Läckage av näringsämnen från svensk åkermark för år 2009 beräknat med PLC5-metodik Beräkningar av normalläckage av kväve och fosfor för 2009. *SMED Rapport Nr 57 2011*.

Blombäck, K., Johnsson, H., Markensten, H., Mårtensson, K., Orback, C., Persson, K., och Lindsjö, A., 2014. Läckage av näringsämnen från svensk åkermark för år 2011 beräknat med PLC5-metodik, *SMED Rapport, in prep, 100 pp*.

Blombäck, K., Börgesen, C. D., Eckersten, H., Gielczewski, M., Piniewski, M., Sundin, S., Tattari, S. & Väisänen, S. 2012. Productive agriculture adapted to reduced nutrient losses in future climate – Model and stakeholder based scenarios of Baltic Sea catchments. *Baltic Compass report*.

Brandt, M. & Ejhed, H., 2002 TRK, Transport – Retention – Källfördelning, Belastning på haven *Naturvårdsverket rapport 5247*, 117 pp.

Bärlund, I. & Tattari, S., 2001. Ranking of parameters on the basis of their contribution to model uncertainty. *Ecol. Model. 142*, 11-23.

Djodjic, F. 2015. Jordartsfördelning och växtnäringstillstånd i svensk åkermark – sammanställning av resultat från Jordbruksverkets nationella jordartskartering. *SLU, Vatten och miljö, Rapport 2015:11.*

Djodjic, F., Blombäck, K., Lindsjö, A., & Persson, K. 2008. Förbättring av beräkningsmetodiken för diffus belastning av fosfor från åkermark. *SMED rapport 2008:20.*

Djodjic, F.& Orback, C. 2013. Förbättrad karta över P-halt i jordbruksmark. *SMED-rapport 139 2013*

Eriksson, J., Andersson, A. & Andersson, R., 1997. Tillståndet i svensk åkermark. *Naturvårdsverket rapport 4778*, Stockholm.

Eriksson, J., Andersson, A. & Andersson, R., 1999. Åkermarkens matjordstyper. *Naturvårdsverket rapport 4955*, Stockholm.

Eriksson, J., Mattsson, L. & Söderström, M., 2010. Tillståndet i svensk åkermark och gröda - Data från 2001-2007. *Naturvårdsverket rapport 6349*, Stockholm.

Havs och vattenmyndigheten, 2016. Näringsbelastningen på Östersjön och västerhavet 2014 – Sveriges underlag till HELCOM's sjätte Pollution Load Compilation. Havs- och vattenmyndighetens rapport 2016:12.

Hoffmann, M., 1999 Assessment of Leaching loss estimates and gross load of nitrogen from arable land in Sweden. Agraria 169. Swedish university of agricultural sciences, Uppsala.

Hoffmann, M. & Johnsson, H., 1999. A method for assessing generalised nitrogen leaching estimates for agricultural land. *Environmental Modeling and Assessment*, 4:35-44.

Hoffmann, M. & Johnsson, H., 2000. Nitrogen leaching from agricultural land in Sweden – Model calculated effects of Measures to reduce leaching loads. *Ambio* 29:67-73.

Jansson, P.-E. & Halldin, S., 1980. Model for annual water and energy flow in a layered soil. In *Comparison of Forest Water and Energy Exchange Models* (ed. S. Halldin), 145-163. International Society for Ecological Modelling, Copenhagen.

Jansson, P.-E., 1991. Simulation model for soil water and heat conditions. Description of the SOIL model. *Report 165*, Department of Soil Sciences, Division of Biogeophysics, SLU, P.O. Box 7014, SE-75007, Uppsala, Sweden. 72 pp.

Johnsson, H. & Hoffmann, M., 1997. Kväveläckage från svensk åkermark – beräkningar av normalutlakning och möjliga åtgärder. *Naturvårdsverket, rapport 4741*, Stockholm.

Johnsson, H. & Hoffmann, M., 1998. Nitrogen leaching from agricultural land in Sweden – Standard rates and Gross loads in 1985 and 1994. *Ambio* 27:481-488.

Johnsson, H & Mårtensson, K., 2002. Kväveläckage från svensk åkermark. Beräkningar av normalutlakning för 1995 och 1999. *Naturvårdsverket rapport nr 5248*. 89 pp.

Johnsson, H., Bergström, L., Jansson, P.-E. & Paustian, K., 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. *Agric. Ecosystems Environ*. 18:333-356.

Johnsson, H & Mårtensson, K., 2006a. Beräkning av effekten på kväveutlakningen av miljöersättningen ”Minskat kväveläckage” år 2001 med utgångspunkt i TRK-beräkningarna för år 1999. *Teknisk rapport 108*. Avd för vattenvårdslära. SLU

Johnsson, H & Mårtensson, K., 2006b. Beräkning av förändringen av kväveutlakningen mellan 1995 och 2003 och den förväntade effekten av åtgärder som föreslagits för minskade utlakningsförluster. Delredovisning av projektet ”beräkningar av kväveutlakningen”. *Teknisk rapport 104*. Avd för vattenvårdslära. SLU

Johnsson, H., Larsson, M., Mårtensson, K. & Hoffmann, M., 2002. SOILNDB: A decision support tool for assessing nitrogen leaching losses from arable land. *Environmental Modelling & Software* 17:505-517.

Johnsson, H., Mårtensson, K., Larsson, M. & Matsson, L. 2006a. Beräkning av kväveutlakningen vid förändrad gödsling för höstvete och vårkorn. *Teknisk rapport 106.* Avdelning för vattenvårdslära, SLU, Uppsala

Johnsson, H., Mårtensson, K., Torstensson, G. & Persson, K. 2006b. Beräkning av normalutlakningen av kväve 2003 för den ekologiskt odlade arealen. *Teknisk rapport 105*. Avdelning för vattenvårdslära, SLU, Uppsala

Johnsson, H., Larsson, M., Brandt, M., Pers, L. & Rosberg, J. 2006c. Framtagning av nytt fosforberäkningssätt för beräkningssystem för diffus belastning, retention och tillförsel till havet för PLC5 rapporteringen 2007. *SMED Rapport Nr 16 2006.*

Johnsson, H., Larsson, M., Lindsjö, A., Mårtensson, K., Persson, K.;& Torstensson, G. 2008. Läckage av näringsämnen från svensk åkermark Beräkningar av normalläckage av kväve och fosfor för 1995 och 2005. *Naturvårdsverket rapport nr 5823*. 152 pp.

Johnsson, H., Lindsjö, A., Mårtensson, K., & Persson, K. 2009. Läckage av näringsämnen från svensk åkermark för år 1999 beräknat med PLC5-metodik. Teknisk rapport 132. Avdelningen för biogeofysik och vattenvårdslära, SLU, Uppsala.

Johnsson, H., Mårtensson, K., Lindsjö, A., Persson, K., Andrist Rangel, Y. & Blomäck, K. 2016. Läckage av näringsämnen från svensk åkermark Beräkningar av normalläckage av kväve och fosfor för 2013. *SMED Rapport nr 189*. 208 pp.

Jones, C.A., C.V. Cole, A.N. Sharpley, and J.R. Williams. 1984. A simplified soil and plant phosphorus model: I. Documentation. Soil Sci. Soc. Am. J. 48:800–805.

Jordbruksverket, 2015. Nationell jordartskartering - Matjordens egenskaper i åkermarken. *Jordbruksverket Rapport 2015:19*.

Jordbruksverket och SCB, 2013. Normskördar för skördeområden, län och riket 2013. *Statistiska meddelanden, JO 15 SM 1301.*

KLS (1965). Kungliga Lantbruksstyrelsens kungörelse med (5) bestämmelser för undersökning av jord vid statens lantbrukskemiska kontrollanstalt och lantbrukskemisk kontrollstation och lantbrukskemisk station med av staten fastställda stadgar. *Kungliga Lantbruksstyrelsens kungörelser mm*.

Knisel, W.G., 1980. CREAMS: a field-scale model for chemicals, runoff and erosion from agricultural management systems. USDA, *Conservation Research Report 26.*

Kyllmar, K., Johnsson, H. & Mårtensson, K. 2002. Metod för bestämning av jordbrukets kvävebelastning i mindre avrinningsområden samt effekter av läckagereducerande åtgärder- Redovisning av projektet ”gröna fält och blåa hav*”. Ekohydrologi 70*, Uppsala.

Kyllmar, K. Mårtensson, K., Johnsson, H. 2005. Model-based coefficient method for calculation of N leaching from agricultural fields applied to small catchments and the effect of leaching reducing measures. *Journal of Hydrology 304:343-354*.

Lantmäteriet. 2015. https://www.lantmateriet.se/sv/kartor-och-geografisk-information/hojddata/GSD-hojddata-grid-2/

Larsson, M., Johnsson, H., Hoffmann, M. & Mårtensson, K., 2002. Technical description of SOILNDB (V. 1.0). Teknisk rapport 64. Department of Soil Sciences, Division of Water Quality Research, SLU, P.O.Box 7072, SE-75007 Uppsala Sweden.

Larsson, M., Kyllmar, K., Jonasson, L. & Johnsson H. 2005. Estimating reduction of nitrogen leaching from arable land and the related costs. *Ambio 34:538-543*.

Larsson, M., Persson, K., Ulén, B., Lindsjö, A. & Jarvis, N.J., 2007. A dual porosity model to quantify phosphorus losses from macroporous soils. *Ecological Modelling* 205:123-134.

Naturvårdsverket, 1997b. Källor till kväveutsläpp. Underlagsrapport. *Naturvårdsverket rapport 4736*, Stockholm

Persson, K., Larsson, M., & Johnsson, H., 2007a. Nutrient Leaching Coefficient Calculating System (NLeCCS) - Technical description. *Teknisk rapport 116.* Avdelningen för vattenvårdslära, SLU.

Persson, K., Larsson, M., Johnsson, H. & Lindsjö, A., 2007b. ICECREAMDB 1.0.34 - Technical description. *Teknisk Rapport 117.* Avdelningen för vattenvårdslära, SLU.

Persson, K., 2009. Automatisering av beräkningsrutiner i NLeCCS. *SMED rapport (avtal: 3080905)*.

Persson, K. 2016. Klimatdatabasen version PLC6. Teknisk dokumentation. Inst. för mark och miljö, SLU, Uppsala.

Posch, M., Rekolainen, S., 1993. Erosivity factor in the Universal Soil Loss Equation estimated from Finnish rainfall data. *Agric.Sci. Finland 2*, 271–279.

Radcliffe, D. E., Reid, D. K., Blombäck, K., Bolster, C. H., Collick, A. S., Easton, Z. M., Francesconi, W., Fuka, D.R., Johnsson, H., King, K., Larsbo, M., Youssef, M.A., Mulkey, A. S., Nelson, N.O., Persson, K., Ramirez-Avila, J.J., Schmieder, F., & Smith, D.R., 2015. Applicability of models to predict phosphorus losses in drained fields: A review. *ASDR*

Rawls, W.J., Brakensiek, D.L., Saxton & K.E., 1982. Estimation of soil water properties. *Transactions of the ASAE* 1316-1320.

Rekolainen, S. & Leek, R. (ed.), 1996 Regionalisation of erosion and nitrate losses from agricultural land in Nordic countries. *Tema Nord 1996:615*, Copenhagen, Denmark.

Rekolainen, S. & Posch, M., 1993. Adapting the CREAMS model for Finnish conditions. *Nordic Hydrol. 24*, 309-322.

SCB, 2013a. Odlingsåtgärder i jordbruket 2012 Träda, slåttervall, vårkorn, havre, höstspannmål samt användning av halm och blast. *Statistiska meddelanden, MI 30 SM 1302.*

SCB, 2013b. reviderad 2014. Sambearbetning av Gödselmedelsundersökningen och Skördeundersökningarna 2011. *PM Lantbruksstatistik 2013:2.*

SCB, 2013c Kväve- och fosforbalanser för jordbruksmark och jordbrukssektor 2011. *Statistiska meddelanden, MI 40 SM 1301.*

SCB, 2014. Gödselmedel i jordbruket 2012/2013. Mineral- och stallgödseltill olika grödor samt hantering och lagring av stallgödsel. *Statistiska meddelanden, MI 30 SM 1403*.

Schmieder, F., Blombäck, K., Persson, K. & Lindsjö, A., 2010. Modeling the effect of buffer strips on surface losses of particulate phosphorus. Proceedings from the 6th International phosphorus workshop (IPW6), Sevilla, Spain,27 September – 1 October 2010.

Sharpley, A.N., Jones, C.A., Gray, C., & Cole, C.V. 1984. A Simplified Soil and Plant Phosphorus Model: II. Prediction of Labile, Organic, and Sorbed Phosphorus. Soil Science Society of America Journal 48(4): 805-809.

Stjernman Forsberg, L., Johansson, G. & Blomberg, M. (2015). Växtnäringsförluster från åkermark 2013/2014. Årsredovisning för miljöövervakningsprogrammet Observationsfält på åkermark. *Swedish University of Agricultural Sciences, Department of Soil and Environment. (Ekohydrologi; 140).*

Tattari, S., Bärlund, I., Rekolainen, S., Posch, M., Siimes, K., Tuhkanen, H.-R. & Yli-Halla, M., 2001. Modelling sediment yield and phosphorus transport in Finnish clayey soils. *Trans. ASAE 44*, 297-307.

Tengdelius Brunell, J., Gustavsson. H., Alavi, G. 2016a. Avrinning beräknad med S-HYPE till PLC6 och jämförelse med PLC5-resultat – Underlagsrapport till Pollution Load Compilation 6. SMED Rapport Nr 185 2016.

Torstensson, G., Persson, K., Johnsson, H., Mårtensson, K., & Larsson, M., 2006. SOILNDB 3.0. *Teknisk rapport 98*. Avdelningen för vattenvårdslära, SLU.

Widén-Nilsson, E., Djodjic, F., Englund, D., Hellgren, S., Liljeberg, M., Olshammar, M., Olsson, H., Orback, C., Tengdelius-Brunell, J. 2016. Kartdata till PLC6 – Underlagsrapport till Pollution Load Compilation 6 rörande markanvändning, vattenförekomstområden, regionsindelning, jordbruksmarkens jordart, lutning och fosforhalt samt medelvärdesberäkningar. SMED Rapport Nr 186 2016.