Wettelijke Onderzoekstaken Natuur & Milieu

Options for closing the phosphorus cycle in agriculture

Assessment of options for Northwest Europe and the Netherlands

WOt-werkdocument 353

J.P. Lesschen, J.W.H. van der Kolk, K.C. van Dijk and J. Willems

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Options for closing the phosphorus cycle in agriculture

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Abstract
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This study assessed which options are available for closing the feed-manure phosphorus cycle in agriculture and their contribution to the reduction of the P surplus and P use efficiency. This was assessed at a national scale for the Netherlands as well as a regional scale for Northwest Europe. No export of animal products, with as a consequence the reduction in livestock numbers, is most effective in reducing external P inputs. An effective option that is easier to implement is the reduction in P excretion through changes in the feed intake. For Nortwest Europe the combination of all five options can lead to a reduction of external P inputs of about 50%. For the Netherlands the combination of the options result in a reduction in external P inputs of 35% and a reduction of the manure export of 26%. The effectiveness of large scale manure treatment in the Netherlands is limited.

Key words: agriculture, feed-manure cycle, nutrient management, phosphorus recycling, resource use efficiency

Authors
J.P. Lesschen – Alterra Wageningen UR
J.W.H. van der Kolk – Alterra Wageningen UR
K.C. van Dijk – Alterra Wageningen UR
J. Willems - PBL

 Alterra Wageningen UR
PO Box 47, 6700 AA Wageningen
Phone: (0317) 48 07 00; e-mail: info.alterra@wur.nl

Netherlands Environmental Assessment Agency (PBL)
PO Box 303, 3720 AH Bilthoven
Phone: (070) 328 87 00; e-mail: info@pbl.nl

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Statutory Research Tasks Unit for Nature & the Environment, P.O. Box 47, NL-6700 AA Wageningen, The Netherlands
Phone: +31 317 48 54 71; e-mail: info.wnm@wur.nl; Internet: www.wageningenUR.nl/wotnatuurenmilieu

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Contents

Summary

In the Netherlands, an intensification of agricultural production has taken place since approximately 1950. This has led to a high production of manure and minerals in areas of the Netherlands where livestock densities are high combined with high application levels of mineral fertiliser. This caused environmental problems due to the emission of nutrients to the air and to surface and ground water systems.

In the Netherlands, as one of the measures to reduce the nutrient surplus from manure and fertiliser, the government decided to aim for feed-manure cycles that should be principally closed on a regional, national or Northwest European level. The question is now how such a closed feed-manure cycle can be best achieved. The feed-manure cycle includes the import of feed from outside the Netherlands, but also the export of the food produced (meat, eggs and dairy products) to other markets outside the Netherlands. Although, a small part of the manure is exported as well, most of the manure which is produced in the Netherlands remains in the country and is used as a fertiliser or is being processed.

The government is focussing on closing the feed-manure cycle for phosphorus (P), since P is a scarce and finite resource in contrast to nitrogen (N) that can be produced artificially or through biological N fixation. This leads to the question which options are available for closing the P cycle in agriculture and what is their contribution to the reduction of the P surplus and P use efficiency. In this study we assessed this issue at two spatial scales: at national scale for the Netherlands as well as regional scale for Northwest Europe (NW Europe).

To assess the effectiveness of the different options, it is necessary to have insight in figures about the number of livestock, import of feed, feed composition, etcetera. In addition, existing environmental policies have to be taken into account. Therefore a reference situation for NW Europe for 2004 and for the Netherlands the year 2009 is used. In this study the options were assessed by the environmental impact assessment models MITERRA-Europe and MITERRA-NL. These models calculate nutrient balances and N and greenhouse gas emissions from agriculture. The focus for this study is on P. To assess which options are most effective in closing the feed-manure P cycle, we defined three parameters: the crop P use efficiency, the animal P use efficiency and external P inputs of the agricultural P-balance. Five options to reduce P losses in agriculture have been designed and assessed for the NW Europe and seven options specific for the Netherlands.

At both spatial scales the option of no export of animal products (100% self-sufficiency), with as a consequence the reduction in livestock numbers, is most effective in reducing external P inputs. However, this option has significant economic impacts, with on average a reduction in livestock numbers of 10% for NW Europe and at the national scale for the Netherlands even a reduction of almost 40%. An effective option that is more easy to implement, probably without any cost or productivity effects, is the reduction in P excretion through changes in the feed intake. This option could reduce the soil P surplus in NW Europe by 23% and for the Netherlands reduce the import of feed from outside the EU by 15% and the export of P manure 18%. At NW European scale the reduction of mineral P fertiliser through balanced fertilisation is also an effective option, which can reduce the soil P surplus by 26%. In the Netherlands this option is less effective due to the already low P fertiliser inputs and the high inputs from manure.

The effect of large scale manure treatment in the Netherlands on the closure of the feed-manure P cycle is limited. Obligatory manure treatment is currently proposed as the alternative for the milk quota and animal production rights for the poultry and pig sector. Due to the lowering of the P application standard, no space is left for additional application of manure P within the Netherlands. This means that most of the P in treated manure is exported. A combination of different options will be most effective in reducing P losses from the feed-manure cycle. For NW Europe the combination of all five options can lead to a reduction of external P inputs of about 50%. For the Netherlands the combination of the six options, excluding the no export of animal products, will lead to a reduction in external P inputs of 35% compared to the 2009 reference, and a reduction of the manure export and treatment of 26%.

However, a fully closed feed-manure P cycle will difficult to obtain on both NW European as well as national scale. For NW Europe the external input of mineral P fertilizer is most important, which cannot be completely replaced by manure and other organic inputs as sewage sludge and compost. In the Netherlands the import of feed from outside the EU is most important, whereas mineral P fertilizer has only a limited contribution, which can be replaced by other P inputs. Reduction of the imported feed quantity is possible, but a completely closed feed-manure P cycle is not possible without a large reduction in animal numbers.

Samenvatting

Vanaf 1950 heeft in Nederland een intensivering plaats gevonden van de landbouwproductie. Dit heeft geleid tot een hoge productie van mest en mineralen in bepaalde gebieden in Nederland waar de vee dichtheid hoog is. Hoge toediening van deze mest leidt tot emissie van nutriënten naar lucht en grond- en oppervlaktewater.

De Nederlandse regering heeft besloten om te streven naar een gesloten voer-mestkringloop, als één van de maatregelen om het nutriëntenoverschot te verminderen. Deze kringloop zou gesloten moeten worden op zowel regionaal, nationaal als Noordwest-Europees niveau. De vraag is hoe deze kringloop op de verschillende schaalniveaus het best kan worden gesloten. De voer-mestkringloop omvat de invoer van grondstoffen van voer van buiten Nederland, maar ook de export van het geproduceerde voedsel (vlees, eieren en zuivel) naar markten buiten Nederland. Het grootste deel van de geproduceerde mest wordt in Nederland gebruikt als meststof of wordt verwerkt, slechts een klein deel van de mest wordt geëxporteerd.

De overheid richt zich bij het sluiten van de voer-mestkringloop op fosfor (P), omdat P een schaarse en eindige hulpbron is in tegenstelling tot stikstof (N) dat kunstmatig of via biologische N-binding kan worden geproduceerd. Dit leidt tot de vraag welke opties er zijn om de P-cyclus in de landbouw te sluiten op verschillende schaalniveaus. In deze studie hebben we ons gericht op het sluiten van de P-kringloop op twee schaalniveaus: nationaal en Noordwest-Europees.

Om de effectiviteit van de verschillende opties te beoordelen, is het noodzakelijk om inzicht te hebben in cijfers over onder andere de omvang van de veestapel, invoer van diervoeders en voersamenstelling. Bovendien moet rekening worden gehouden met bestaand beleid. Als referentie situatie is voor Noordwest-Europa het jaar 2004 gebruikt en voor Nederland 2009. In deze studie zijn de verschillende opties doorgerekend met de simulatie modellen MITERRA-Europe en MITERRA-NL. Deze modellen berekenen de nutriëntenbalansen en de emissie van broeikasgassen door de landbouw. Om te beoordelen welke opties het meest effectief zijn voor het sluiten van de voer-mest-kringloop van P, zijn drie parameters gedefinieerd: de P-gebruiksefficiëntie van het gewas, de P-gebruiksefficiëntie van het dier en de externe aanvoer van P. Vijf opties zijn gedefinieerd om de P-verliezen op Noordwest-Europese schaal te beperken en zeven opties specifiek voor Nederland.

Voor beide ruimtelijke schalen is de optie ‘geen export van dierlijke producten’ (100% zelfvoorziening), waardoor de veestapel moet krimpen, het meest effectief om de externe aanvoer van P te beperken. Echter, uitvoeren van deze optie heeft tot gevolg dat de veestapel in Noordwest-Europa met gemiddeld 10% daalt en in Nederland zelfs met bijna 40%. Dit heeft belangrijke economische gevolgen. Een andere optie die eenvoudiger te implementeren is, en waarschijnlijk zonder enige kosten of vermindering van de productie gepaard gaat, is de vermindering van P-excretie door verandering van de voersamenstelling. Deze optie zou het P-bodemoverschot in Noordwest-Europa verminderen met 23% en in Nederland zou dit leiden tot een vermindering van invoer van grondstoffen voor veevoer van buiten de EU met 15% en de export van mest met 18%. Op Noordwest-Europese schaal is de vermindering van minerale kunstmest via een meer evenwichtige bemesting ook een effectieve optie, waardoor het P-bodemoverschot met 26% kan verminderen. In Nederland is deze optie minder effectief doordat in Nederland al relatief weinig P-kunstmest wordt toegediend.

Het effect van grootschalige mestverwerking in Nederland op het sluiten van de P-cyclus lijkt beperkt. Verplichte mestverwerking wordt momenteel door de regering voorgesteld als maatregel om het afschaffen van het melkquotum en de productierechten voor dieren voor de pluimvee- en varkenssector te compenseren. Door verlaging van de P gebruiksnorm is geen ruimte voor meer toepassing van mest binnen Nederland. Dit betekent dat de meeste P van verwerkte mest moet worden uitgevoerd. Een combinatie van verschillende opties lijkt op basis van de modelberekeningen het effectiefst voor het verminderen van P-verliezen in de voer-mestkringloop. Voor Noordwest-Europa kan een combinatie van alle vijf opties leiden tot een vermindering van externe P-invoer met ongeveer 50%. Voor Nederland leidt combinatie van alle maatregelen – uitgezonderd geen uitvoer van dierlijke producten – tot een vermindering van de P-invoer met 35% ten opzichte van het referentie jaar 2009, en een vermindering van de uitvoer van mest en mestverwerking met 26%.

Echter, een volledig gesloten voer-mestkringloop voor P zal moeilijk te bewerkstelligen zijn op zowel Noordwest-Europese als Nederlandse schaal. Voor Noordwest-Europa is de aanvoer van minerale fosfor bepalend, aangezien deze niet volledig kan worden vervangen door mest en andere organische materialen zoals zuiveringsslib en compost. In Nederland levert de invoer van grondstoffen voor veevoer van buiten Europa de belangrijkste bijdrage aan het P-overschot, terwijl minerale kunstmest slechts een beperkte bijdrage levert, omdat deze kan worden vervangen door andere P-houdende stoffen. Vermindering van de ingevoerde hoeveelheid voer is mogelijk, maar een volledig gesloten voer-mestkringloop op basis van P is alleen mogelijk als er een forse krimp in de veestapel zal plaatsvinden.

1 Introduction

1.1 Background

In the Netherlands, an intensification of animal production has taken place since approximately 1950. This development has led to a high production of manure in areas of the Netherlands where the intensity of farms are high, especially in the southeastern provinces with mainly sandy soils. This surplus of manure production causes environmental problems due to the emission of nutrients as nitrogen (N) and phosphate (P_2O_5) to the air and to surface and groundwater systems.

In the past, policies and regulations to govern the management and utilization of manure were enacted. Historically the implementation of manure management policies and other legislations of the EU (e.g. the Nitrates Directive) have led to an improvement of the groundwater quality and reduced nitrogen emissions to the air (i.e. ammonia and nitrous oxide). However, the rate of improvement has declining over time.

As one of the measure to reduce the manure problem, the Dutch government decided that the 'feed-manure cycle' should be closed on a regional, national or Northwest European scale. This goal brings along the question how such a closed feed-manure cycle can best be achieved. The feed-manure cycle includes the feed import from outside the Netherlands, but also a large part of the food produced (meat, eggs and dairy products) are exported to other markets outside the Netherlands. Although a small part of the manure is exported as well (e.g. incinerated poultry manure), the majority of the manure which is produced in the Netherlands remains in the country. This trade means that the feed-manure cycle is not closed on a national scale. Since a significant part of the feed is imported from outside Europe, the cycle is not closed on a European scale either. In regions in other countries in Northwest Europe there are also large concentration of livestock with consequent manure surplus. At the same time there are other areas with a need for nutrients and thus manure. This imbalance bring along the question whether feed-manure cycles can be closed at a Northwest European scale.

Phosphorus (P) is essential for all life and is a key ingredient in fertilisers to sustain high crop yields. Phosphorus has no substitute in food production, and therefore securing sufficient P for agriculture is critical for future food security. However, since the green revolution the main source of phosphorus is mined as phosphate rock. These primary sources are in principle non-renewable at a human time scale and will become increasingly scarce and expensive (Cordell *et al.*, 2011). Above all, Europe has only little own minable reserves in Finland making the continent dependent on imports from a few countries such as Morocco (De Ridder *et al.,* 2012). Improved use efficiency in agriculture (and other key stages of the food chain), could significantly reduce the global demand for P (Cordell *et al.,* 2009). In policy making there is also a strong focus on P since it is a key trigger nutrient in eutrophication of surface waters and seas. Schröder *et al.* (2011) showed that the amounts of P applied in agriculture could be considerably smaller by optimizing land use, improvement of fertiliser recommendations and application techniques, modified livestock diets, and adjustment of livestock densities to available land.

The main two research questions in this study were: (1) which options are available for closing the phosphorus cycle in agriculture and (2) what is their contribution to the reduction of the phosphorus surplus. In this study we assessed this issue at two spatial scales: at the national scale for the Netherlands as well as regional scale for Northwest Europe (NW Europe), which comprises the following countries: United Kingdom, Ireland, Netherlands, Belgium, Luxembourg, France, Germany and Denmark. To assess the effectiveness of the different options, it is necessary to get a clear quantitative picture about the import of feed, the composition of the feed materials, the number of cows, pigs and poultry, etc.. In addition, existing and future policies regarding manure and nutrient management have to be taken into account.

1.2 Objectives

The main purpose of this study was to explore which options can be useful to close the phosphorus cycle in agriculture. We distinguished two different spatial scales of closing the cycle: the Netherlands and Northwest Europe.

The following underlying objectives have been defined:

- To calculate the P balance and flows and identify where main losses occur for the reference situation. For the Netherlands we used the year 2009, while for NW Europe 2004 was used, since feed data were only available for that year.
- To define options that can be taken to reduce P losses and close the P cycle at the different scales.
- To assess the impact of the options on the P balance, the P use efficiency and the amount of external P inputs into the agricultural system.

The impact of the selected options were assessed by using the environmental impact assessment models MITERRA-Europe and MITERRA-NL. Both models calculate nutrient balances for N and P, and N and greenhouse gas emissions from agriculture. In this study we focussed on phosphorus, since phosphorus is an essential, scarce and finite resource that has no global atmospheric cycle. This is in contrast to nitrogen since that element is available in the atmosphere and can be fixed by humans using the energy intensive Haber-Bosch process, or by plants, algae and cyanobacteria that have the ability of biological N fixation. In addition, in policy making there is also a strong focus on P. Nevertheless, the models assess the effects on nitrogen as well, but those results are not included in this report.

In Chapter 2 the models MITERRA-Europe and MITERRA-NL are described. Chapter 3 describes the five options which are defined for NW Europe and gives the results. In Chapter 4 seven options for the Netherlands are described including the model results. Conclusions are given in Chapter 5.

2 Model description

2.1 MITERRA-Europe

MITERRA-Europe is an environmental impact assessment model, which calculates nutrient balances and nitrogen and greenhouse gases (GHG) emissions on a deterministic and annual basis using emission and leaching factors (Velthof *et al.,* 2009; Lesschen *et al.,* 2011a). MITERRA-Europe is partly based on the models CAPRI (Britz and Witzke, 2008) and GAINS (Klimont and Brink, 2004), supplemented with an N leaching module, a soil carbon module and a mitigation module for GHG and ammonia (NH_3) emissions and nitrate (NO_3) leaching measures. The database of MITERRA-EUROPE is on the national and regional level (NUTS 2, according Nomenclature of Territorial Units for Statistics in the EU) and includes data of nutrient inputs and outputs, livestock numbers, land use, crop types, soil type, and emission factors for NH_3, N_2O, and NO_X, and leaching factors for NO_3.

Crop areas were derived from CAPRI at NUTS 2 level, which are mainly based on Eurostat data, and crop yields from FAOSTAT at national level as EUROSTAT data was incomplete. Grassland yields and N contents of grassland were estimated using the methodology of Velthof *et al.* (2009), because grassland yields are not available from statistics. The number of livestock in each year was derived from GAINS at national level, and distributed over the NUTS 2 regions according to CAPRI data. Data on annual N and P fertiliser consumption and primary animal production were collected from FAOSTAT. N excretion of livestock was obtained from the GAINS model (Klimont and Brink, 2004) and P excretion was calculated via the N-P ratio per livestock category, based on OECD data and Sheldrick *et al.* (2003).

The total manure production was calculated at the NUTS 2 level from the number of animals and the N and P excretion rates per animal and then corrected for N losses in housings and storage. A method was developed to distribute the manure over crops taking account of the maximum manure application of 170 kg N/ha or higher in case of a derogation. Mineral N and P fertiliser was distributed over crops relative to their N and P demand, taking into account the amount of applied manure and grazing manure and their respective fertiliser equivalents (Velthof *et al.,* 2009). Further nitrogen inputs include biological N fixation, which is estimated as a function of land use and crop type (legumes) and nitrogen deposition that is derived at NUTS 2 level from EMEP (EMEP, 2010). For this study we also included the input of nutrients from compost and sewage sludge, based on Barth *et al.* (2008) and Milieu Ltd *et al.* (2009) respectively. However, due to lack of data at the sub-national level only an average application per hectare per country was used. See Figure 1 for a schematic overview of all P flows in the model.

Feed consumption per animal type was also derived from the CAPRI model. The assigned feed properties, i.e. dry matter, N and P content, are described in Lesschen *et al.* (2011a). We assumed the nutrient content of each feed type to be equal among all EU countries. Only for grass country specific N content data was available based on Velthof *et al.* (2009). In the feed calculation we made a distinction between feed that is produced within the EU and feed that is imported from outside the EU. For this last category we assumed that it comprises all soybean, cassava and imported molasses and 25% of the other protein rich feed and 25% of the corn gluten feed.

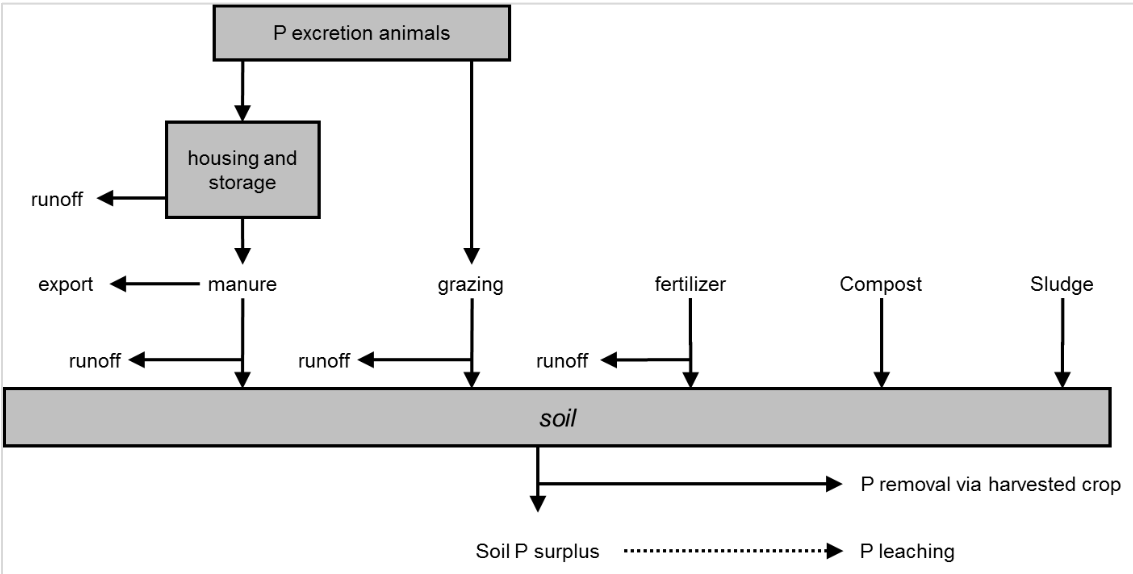

Figure 1. Phosphorus flows in MITERRA for the soil P balance (note that P leaching is not included in MITERRA)

2.2 MITERRA-NL

We used the MITERRA-NL model to assess the options for closing the P cycle in agriculture for the Netherlands. This model is based on MITERRA-Europe, but uses data and emission factors that have been made more specific for the Netherlands. Also the spatial resolution is much more detailed, instead of the province level (n =12) as in MITERRA-Europe the MITERRA-NL version calculates at postal code level (n = 4004). MITERRA-NL simulates the N and P balance, emissions of NH_3, N_2O, NO_X, and CH_4, leaching and runoff of N, NO_3 concentration in groundwater and changes in soil and biomass carbon stocks at a postal code level.

MITERRA-NL was parameterised with emission factors and data sets of the Netherlands, including crop and livestock statistics, N and P excretion values for livestock, yields, and N and P contents of crops. Leaching was calculated using NO_3 leaching fractions (Fraters *et al.,* 2007; Schröder *et al.,* 2007), and NH_3 and N_2O emissions using emission factors used in the Netherlands for reporting to the NEC and UNFCCC (Velthof and Mosquera, 2011; Velthof *et al.,* 2012). A further description of MITERRA-NL can be found in Lesschen *et al.* (2011b) and Van der Hilst *et al.* (2012).

Input data

The main input data of the model are crop areas and livestock numbers, which were derived from the Geographical Information system Agrarian Businesses database (GIAB) and the 'Basis registratie percelen' (BRP) on postal code level. The GIAB data on animal numbers for 35 livestock categories is from 2009, whereas the crop areas (38 crop types, including 3 types of grassland) from BRP are from 2007. Crop yields are based on the Dutch Central Bureau of Statistics (CBS) 'oogstramingen' from 2009, which are available for the main arable crops at province level and for other crops at national level. The yield of grassland is based on Aarts *et al.* (2008) and Zwart *et al.* (2010). Nitrogen contents of crops are based on Van Dijk & Schröder (2007) and phosphorus contents on Ehlert *et al.* (2009).

The total manure production is calculated by multiplying the number of animals with the N and P excretion rates, which were derived from the working group on uniforming manure production data

(WUM, 2009). The following manure types are distinguished: liquid cattle manure, solid cattle manure, liquid pig manure, poultry manure, and manure from other animals. Besides the main manure types also several manure products are distinguished that are formed after manure treatment such as mineral concentrates, see Lesschen *et al.* (2011b).

The distribution and application procedure for manure and mineral fertiliser in MITERRA-NL is based on the Dutch manure policy, which includes three application standards:

- Animal manure: maximum of 170 kg N per ha based on the Nitrates Directive, except for farms that are granted a derogation by the European Commission. In that case the maximum for grassland and fodder maize is 250 kg N per ha from grazing animals.
- Total nitrogen standard: maximum amount of mineral and organic nitrogen, which depends on the combination of crop and soil type. The standard is based on effective nitrogen (*werkingscoefficiënt*), which is 100% for mineral fertiliser and 35% -65% for manure, depending on manure and animal type
- Phosphate standard: maximum amount of mineral and organic phosphate, based on land use (grassland or cropland) and the phosphorus status of the soil (see Figure 2 for a map).

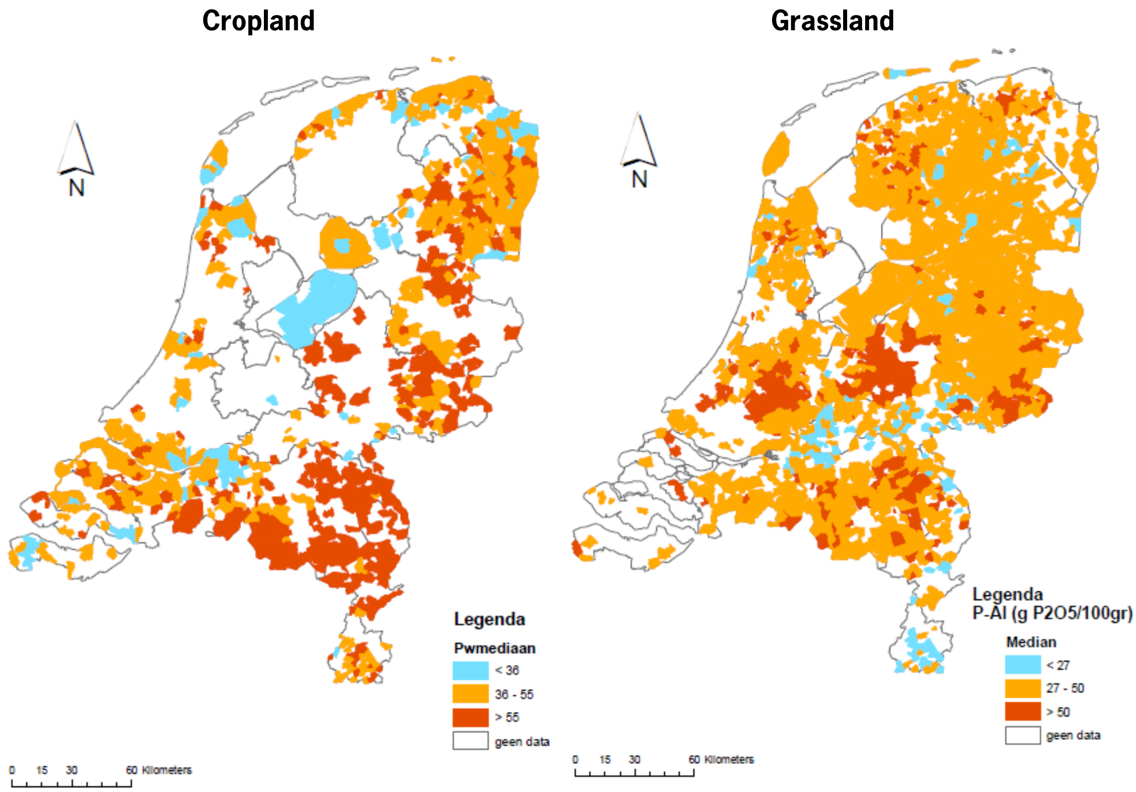

Figure 2. Median value of the phosphorus (P) status of at postal code level for cropland (Pw value, right) and grassland (P-Al value, left), based on BLGG soil analysis from the period 1996-2000 for grassland and 2000-2004 for cropland (Reijneveld et al., 2010)

The available space for the application of manure and mineral fertiliser is calculated at the province level, taking into account the area under derogation (based on 2009 data) and the different crop and soil types. The standard for total nitrogen is normally not completely filled with animal manure, as this is from an agronomic point of view not appropriate for several crops. Therefore a manure acceptance factor was set for each crop type, defined as percentage of the maximum animal manure application standard (100% for grassland and fodder maize, 80% for wheat, sugar beet and potato, 50% for vegetables, 30% for barley and 25% for other crops.

The manure production is calculated and distributed at province level, taking into account three application standards. In case of a manure surplus, the remaining manure is distributed in provinces where there is still space for manure application. Remaining manure nutrient surpluses are then assumed to be exported or used outside agriculture, see Lesschen *et al.* (2011b) for further details.

For this study we included new feed intake data in MITERRA-NL. The data have been derived from the CBS, which distinguishes 41 feed types for which the intake per animal and the nutrient content is provided. These data are also used for the calculation of the livestock excretions, and consequently the total manure production. However, for the concentrate feed no further specification of the feed ingredients is provided. Based on data of the Dutch Feed Industry Association (NEVEDI) for the composition of concentrate feed, a distinction is made between imported and locally produced feed. Based on these data we assumed that 73.3% of all concentrate feed is derived from imported feed ingredients. Unfortunately no data is available to further specify this to the different animal categories.

3 Assessment for Northwest Europe

3.1 Description of reference situation

For this study we defined Northwest Europe as the area comprised by the following countries: United Kingdom, Ireland, Netherlands, Belgium, Luxembourg, France, Germany and Denmark. These countries comprise a large part of the total livestock production in the EU-27 since they cover 53% of the total livestock expressed in livestock units. The total utilized agricultural area (UAA) in these eight countries is about 73 million ha, which is 39% of the total UAA in the EU-27.

The livestock densities are highest in the Netherlands and Belgium, but also Denmark and some regions in Germany and France have high livestock densities (Figure 3). Cattle production, both dairy and beef, is most intensive in the Netherlands and Belgium, and also in some regions of Germany, France and Ireland. Intensive pig farming is more dispersed with the highest densities in Denmark, Germany, the Netherlands and Belgium. Large scale intensive poultry farming mainly occurs in Belgium, the Netherlands and the Bretagne region of France. The total number of livestock per country in 2004 is shown in Table 1.

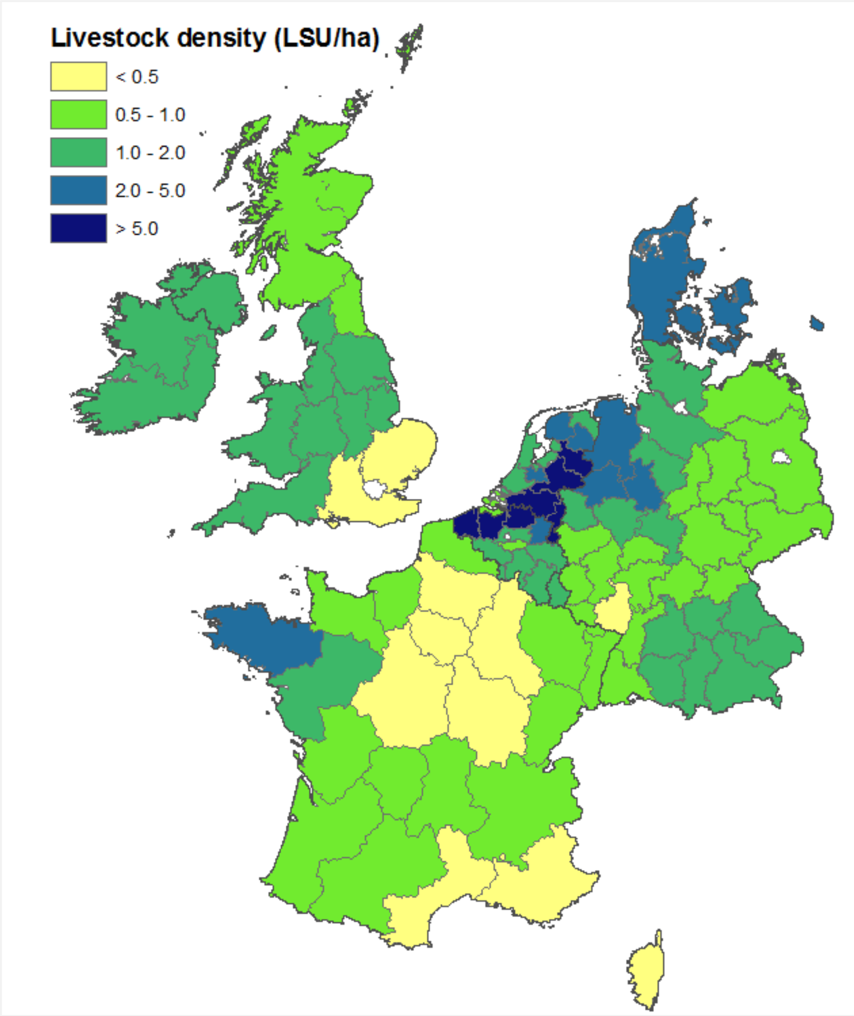

Figure 3. Livestock densities per NUTS 2 region in Northwest Europe

Table 1. National livestock numbers (x 1000) per animal type for the NW European countries in 2004

Country	Dairy cows	Other cattle	Pigs	Poultry	Other livestock
Belgium	563	2344	7266	39728	205
Germany	4235	9315	25218	108890	2688
Denmark	558	942	13079	18146	2679
France	3965	15503	15885	258076	10791
Ireland	1122	5090	1695	16057	6515
Luxembourg	43	156	87	73	9
Netherlands	1450	2332	12107	103646	2699
United Kingdom	2071	8307	4847	175620	34189

Figure 4 shows the soil P balance for each of the eight countries from NW Europe, as calculated by MITERRA-Europe for the year 2004. Belgium and the Netherlands had on average a much higher input of P to the soil compared to the other countries. Applied manure was the largest source, followed by grazing manure and mineral fertiliser. Deposition, compost and sewage sludge are in all countries only a minor source of phosphorus. The P surplus, defined as the difference between the P inputs and the crop uptake, was also highest in Belgium and the Netherlands (about 25 kg P/ha).

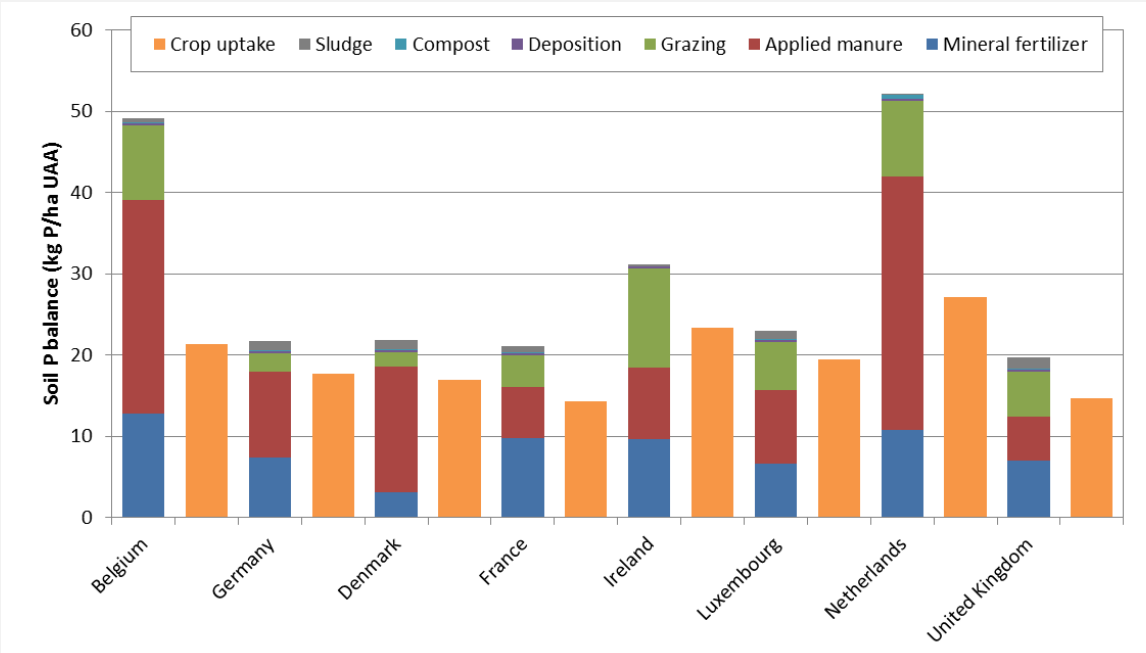

Figure 4. Soil P balance per country for the 2004 reference situation

3.2 Options for reducing P losses

We selected the following P losses reduction options for Northwest Europe:

1. Reduction of mineral fertiliser use: for this option we assumed balanced fertilisation, i.e. the amount of mineral fertiliser is based on the nutrient demand by the crops, corrected for the input via manure.
2. Reduction of P excretion: in this option part of the feed intake will be replaced by feed which contains less P.
3. Maximum recycling of human organic waste (i.e. green waste, biowaste and sludge), which is used as fertiliser in agriculture.

4. No export of animal products outside NW Europe: in this option NW Europe is self-supporting with regard to meat, dairy products and eggs. No changes in diet are foreseen in this option, but the animal population has to be reduced.
5. Replacement of soybean feed ingredients and inorganic feed phosphate by meat and bone meal.

3.2.1 Reduction mineral fertiliser use to balanced fertilisation

Introduction

Phosphorus use efficiency in crop production can still be increased in Northwest Europe, as farmers still often apply more nutrients in fertiliser and manure than actually needed by the crop. Schröder *et al.* (2011) discuss several measures that can be used to improve the P use efficiency in agriculture. Several of these measures are related to decreasing mineral fertiliser use, e.g. improving fertiliser recommendations, fertiliser placement methods and adjusting inputs to outputs. We have combined these measures in one option of balanced fertilisation that can be assessed by the MITERRA-Europe model.

Parameterisation

By using the MITERRA-Europe model we calculated the nutrient demand per crop on the basis of balanced fertilisation. This procedure is described in detail for N in Velthof *et al.* (2009). In the case of P we assumed no overfertilisation, i.e. only the amount of P that is removed by the harvested crop product is replaced by fertiliser. First the amount of manure is distributed, after which the remaining demand for mineral fertiliser P is calculated. We calculated the final reduction of mineral fertiliser use by comparing this 'balanced fertilisation' demand to the amount of mineral fertiliser in the reference situation of 2004.

Results

Balanced fertilisation would lead to a decrease in mineral P fertiliser use for NW Europe from 614 kton P to 488 kton P, which is a reduction of 20%. For the entire EU-27 the reduction would be even 42% from 1491 kton P to 868 kton P. The reduction is lower for NW Europe, since these countries have a relatively lower P fertiliser use compared to the crop uptake due to the high input of animal manure. In addition in southern Europe the P fertiliser application is relatively high since the calcium rich soils fix phosphorus and make it unavailable for crop uptake. For some NW European countries (e.g. Denmark and Germany) the soil P balance is already (nearly) closed at country level, and therefore the balanced P fertilisation might even lead to an increase in mineral P fertiliser. In theory the mineral P fertiliser use could be even further reduced when all P in manure from grazing animals and manure application would be distributed according to the demand. This would lead to a reduction in mineral P fertilizer of 50% (305 kton P) for NW Europe.

3.2.2 Reduction of P excretion

Introduction

This option aims to reduce the P excretion through changes in the feed intake. The ability of livestock, especially non-ruminants, to absorb phosphorus from feed is limited. To avoid animal production losses from possible P deficiencies, livestock farmers select feed types with high P concentrations or add inorganic feed phosphates to feed baskets (Schröder *et al.,* 2011).

Knowlton *et al.* (2004) reviewed a range of options available to reduce the P content of manure of monogastric and ruminant species. These options include more accurate interpretation of published P requirements, more precise diet formulation, and utilization of exogenous phytase or low-phytic acid grains in monogastric diets. Also improved grouping strategies to decrease variation within groups of animals, and reduced feed wastage will reduce the P content of manure. The authors conclude that overall the strategies may decrease the P content of manure by 40 to 60% in swine and poultry and by 25 to 40% in ruminants. Currently, there is no incentive for livestock farmers to decrease P excretion, since there is not (yet) an accounting system based on P content, and costs savings are negligible.

Parameterisation

According to Van Krimpen *et al.* (2010) the technical potential to reduce P excretion without negative effects on productivity is estimated at 20% for the Netherlands. It is not certain whether this also applies to other NW European countries, but we assumed that feed concentrate production is similar in other livestock intensive countries in NW Europe. A reduction of P in feed concentrates should be possible without great extensive effort in technical improvements. The production process of feed concentrates can remain the same, only P content of the feed ingredients should be taken into account and less or no feed phosphate should be added. We assumed that P excretion for pigs and poultry is reduced by 20%, and for cattle by 10%, since the share of concentrates in their feed basket is much smaller, and reducing P content of grass and other fodder is more difficult to obtain.

The total use of inorganic feed phosphates (IFP) in the EU is estimated at 1.4 million tonnes in 2005, which is 0.25 Mton expressed in P (CEFIC/IFP, 2009). The use of IFP per livestock category differs per country. The CEFIC-IFP report provides some data, but no complete overview for the individual EU Member States is available. Therefore the total amount of IFP was distributed over the countries and animal types based on the ratio of concentrate feed use, which includes the protein rich feed energy rich feed and other feed. For the option reduced P excretion we assumed that the intake of IFP is reduced by 50%, whereas the remaining reduction of the P excretion is due to a reduction of the P content in feed concentrates, which is further split in imported and local feed according to a ratio of 50%.

Results

The total feed P intake for NW Europe was about 1,330 kton P in 2005, of which 132 kton P is coming from IFP. The CEFIC IFP (2009) report estimated the total feed P intake at 2,250 kton P for the EU, of which roughages comprise 40%, home grown cereals 7%, purchased feed materials 12%, compound feed 30% and inorganic feed phosphate 11%. These values are well in line with the results from the MITERRA-Europe model. For the option of reduced P excretion in NW Europe the total P excretion decreases from 954 kton P to 838 kton P (12%).

3.2.3 Maximum recycling of human organic wastes

Introduction

Improved recycling and use of human organic wastes can reduce the demand for mineral P fertiliser and increase the nutrient use efficiency of the total food system. Organic waste can be divided in three types, i.e. sewage sludge, greenwaste and biowaste.

Sewage sludge has valuable agronomic properties in agriculture and may be used provided that the Member State concerned regulates its use. Currently sewage sludge is not allowed in all countries as fertiliser (e.g. the Netherlands), because of environmental and health risks from heavy metals and pathogens. The European Union regulates the use of sewage sludge in agriculture to prevent harmful effects on soil, vegetation, animals and humans. In Council Directive 86/278/EEC provided maximum values of concentrations of heavy metals and bans the spreading of sewage sludge when the concentration of certain substances in the soil exceeds these values. Sludge must be treated before being used in agriculture but the Member States may authorise the use of untreated sludge if it is injected or worked into the soil. Besides direct use of sewage sludge, which in some countries is not allowed, P can also be recovered from waste water and sewage sludge to produce mineral P fertilisers. There are already several initiatives to recover P from wastewater and sewage sludge. Potential processes include struvite and dicalciumphosphate production from wastewater treatment plants (see e.g. Le Corre *et al.,* 2009) and P recovery from ashes after incineration of (composted) sewage sludge ('thermal route'). However, most of these P recovery processes are still at pilot scale and cannot provide significant amounts of P fertiliser in the near future compared to present use.

The total annual arising of biodegradable solid waste (BSW) in the EU is estimated at 77-102 million ton food and garden waste included in mixed municipal solid waste and up to 37 million ton from the food and drink industry. There are two major streams, green waste from parks, gardens etc. and kitchen waste. Waste management options for BSW include, collection (separately or with mixed waste), anaerobic digestion and composting, incineration, and landfilling (European Commission, 2008). Composting is the biodegredation of organic matter through a self-heating, solid phase, aerobic process. This converts organic matter into a stable humic substance. Compost additions to soil have the potential to i) improve soil physical conditions increasing resistance to erosion, improving soil workability and water infiltration and water holding properties, ii) improve soil fertility, iii) increase soil biodiversity and iv) sequester carbon in the soil (Barth *et al.,* 2008). Standards on the use and quality of compost exist in most Member States, but differ substantially, partly due to differences in soil management policies. While there is no comprehensive EU legislation, certain rules regulate specific aspects of BSW treatment, biogas production and compost use (e.g. the Organic Farming Regulation and eco-labels for soil improvers).

Parameterisation

For sewage sludge we have based our data on a European study by Milieu Ltd *et al.* (2009) that collected data on the total amount of sewage sludge produced and the amount used in agriculture (Figure 5). Presently, in most countries only a small fraction or no sewage sludge is currently used in agriculture. The general trend is a decrease in this use in favour of more incineration. However, in a few large countries, e.g. Spain, France and United Kingdom, still a large fraction of sewage sludge is used directly or indirectly in agriculture. The P content of the sewage sludge was derived at country level from Milieu Ltd *et al.* (2009). For countries with no data available we assumed the average of the available data (33 g P/kg DM). The definition of agricultural use is unclear and broad, since sewage sludge can be applied to crops, fodder, tree nurseries, forestry etc. For this reason we assumed that 80% of the produced sewage sludge could potentially be used for agriculture and replace mineral fertiliser.

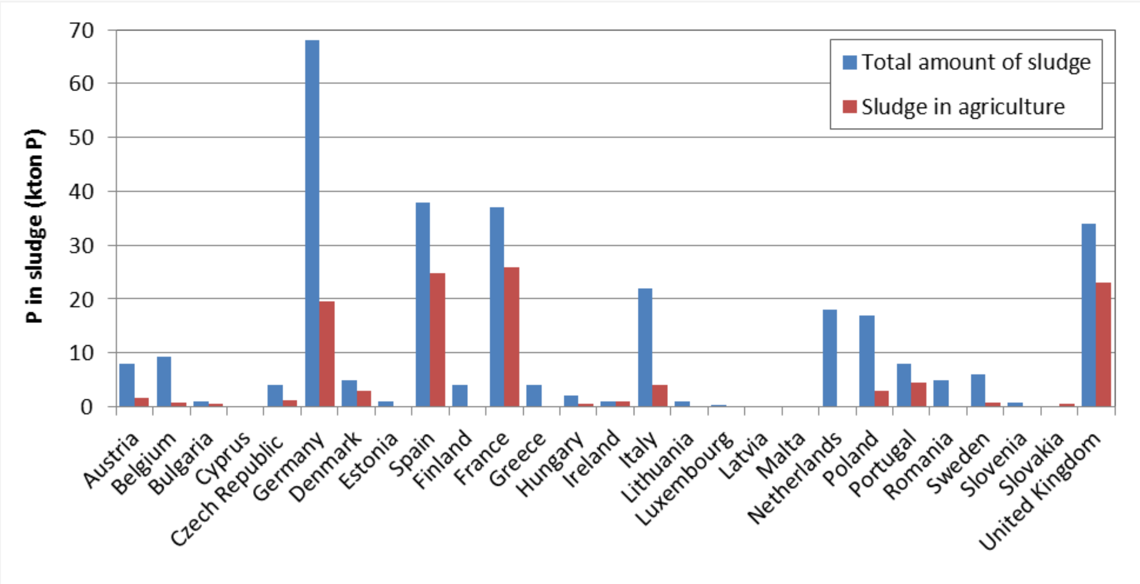

Figure 5. Sewage sludge production and current use in agriculture expressed in P for the EU-27 Member States in 2004 (based on Milieu Ltd et al., 2009)

The compost data were derived from Barth *et al.* (2008) to specify the current amount of organic waste that is collected, the amount of compost used and the total potential amount of organic waste material for recycling (Figure 6). Based on the average of Dutch and Belgian data on compost composition (Table 2 and Table 3) the average P content of biowaste compost was set at 1.67 kg P/

ton compost fresh matter (FM), whereas for green waste compost it is 0.98 kg P/ton compost (FM). For this option of maximum recycling of organic waste streams, we assumed that 70% of the potential amount of organic waste would be available for composting taking quality of the organic waste streams into account.

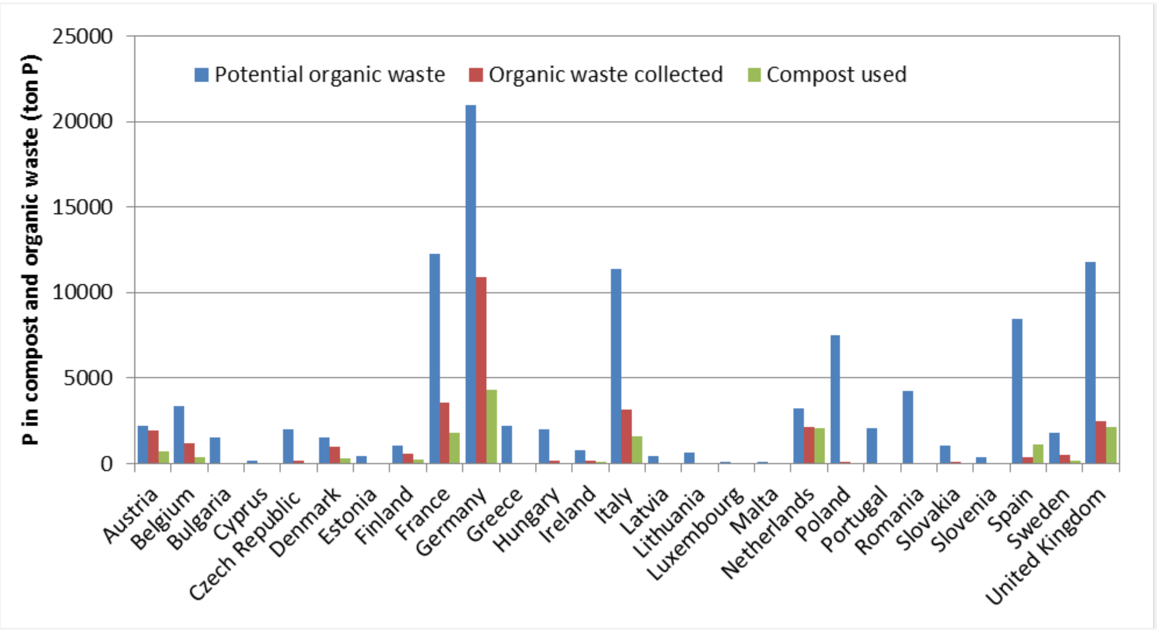

Figure 6. Total quantities of P in produced compost, collected organic waste and the potential amount of organic waste that can be collected for the EU-27 Member States in the year 2004

Table 2. Properties of average compost based on green and bio waste in the Netherlands in kg per ton FM (Van Dijk & Van Geel, 2010)

	Dry matter	**Organic matter**	**N total**	**P_2O_5**	**K_2O**
Biowaste compost	650	190	8.5	3.7	6.4
Champost	350	220	5.8	3.6	8.7
Green compost	598	186	5.1	2.2	4.2

Table 3. Properties of average compost and based on green and bio waste in Belgium (VLACO, 2009), content expressed in dry matter

	Dry matter	**Organic carbon**	**N total**	**P_2O_5**	**K_2O**
Biowaste compost	590	200	12.4	6.69	5.7
Green compost	700	260	6.75	3.28	9.9

Barth *et al.* (2008) also analysed data on compost market sectors from 12 EU-countries for which information was available. Those countries represent approximately 80% of the EU compost production. The average distribution of the market share shows that currently about 50% of the compost with increasing tendency is used in agriculture. However, there is considerable variation among countries. In Belgium only 20% of the compost produced is used in agriculture, most is used in public green and pottery soil. In the Netherlands on average 55% of the produced compost is used in agriculture and horticulture (Werkgroep Afvalregistratie, 2009). For the current situation we assumed that 50% of the amount of compost produced is used in agriculture. For the option of maximum recycling of organic waste we assumed that the potential use of compost in agriculture increases to 70% of the total potential compost production.

Results
The total amount of P in sewage sludge that is currently used in agriculture is estimated at 73 kton P for NW Europe. This is 42% of the total sludge production in these countries. If the use of sewage sludge in agriculture would be increased to 80% of the total production, the total input would be 139 kton P, which would save 65 kton P as mineral fertiliser.

The total amount of P in compost that is currently used in agriculture is estimated at 5.6 kton P for NW Europe. Compared to the total input of P via mineral fertiliser and manure, this contribution is still very minor. If recycling of organic waste would be maximised, i.e. 70% of all organic waste will be composted, and the use of compost in agriculture would increase to 70%, the total input would be 26.5 kton P, which would save an additional 21 kton P as mineral fertiliser. Thus the potential reduction in P fertiliser use through maximum recycling of organic waste streams (sewage sludge and compost) would be 86 kton P, which is a reduction of 14% compared to the mineral fertiliser use in 2004.

3.2.4 No export of animal products outside NW Europe

Introduction
One of the main options to close the feed manure cycle is to match livestock production with the demand for livestock products in a certain region. In NW Europe there is intensive livestock production and for most livestock products the production is higher than the consumption, which means that part of the livestock sector is producing for export markets. In this option the number of animals is reduced to the level that would be needed to feed the entire human population of the eight NW European countries and consequently no longer produce animal products for export.

Parameterisation
Based on the FAO food balance sheets the consumption of livestock products in the eight NW European countries has been calculated based on average 2003-2005 data. These values have been compared with the production of livestock products (Table 4). For all livestock products, except for mutton and goat meat, the eight NW European countries produce more than is needed for own consumption. There is especially overproduction of pork and milk in NW Europe. Based on this overproduction the required reduction in livestock numbers was calculated to match the consumption of livestock products in NW Europe.

Table 4. Animal product production, consumption, overproduction and reduction in livestock numbers for the option of self- sufficiency in NW Europe in 2004

Animal product	**Production**	**Consumption**	**Overproduction**	**Reduction livestock numbers**
	kton	kton	%	%
Beef	4808	4645	3.5	3.4
Pork	11799	9587	23.1	18.7
Poultry meat	5798	5219	11.1	10.0
Mutton and goat meat	580	698	-16.9	0.0
Milk	92779	62394	26.6*	21.0
Eggs	3256	3007	8.3	7.6

** The overproduction for milk is less compared to the consumption, since additional to the human consumption 10910 kton milk is used for animal feeding*

The relative reductions in livestock numbers were equally spread over the eight NW European countries. Based on these reductions, the MITERRA-Europe model was run, with reduced number of animals, feed intake and livestock products. All other parameters, e.g. land use, remained the same, which is an oversimplification, as in reality land used for fodder production might be converted to other crops. For the reduction in animal feed consumption we assumed that the proportional decrease is stronger for imported feed and inorganic feed phosphate, since local feed production will remain. For both categories we assumed a decrease of 50% compared to the 2004 reference.

Results

As a result of the reduction in animal numbers the total P excretion is reduced by 10%, which leads to a decrease of the annual soil P surplus of 93 kton P. Since feed P intake is also reduced, the use of IFP and imported feed from outside the EU can be halved to respectively 68 kton P and 66 kton P. Whether these reductions can be realised in practice is uncertain and depends very much on the willingness of feed companies and farmers to change the composition of feed concentrates towards more locally produced feed ingredients.

3.2.5 Replacement of soybean and feed phosphate by meat and bone meal

Introduction

There are a number of waste streams from agriculture and by-products from food production that could recycle significant quantities of phosphorus. One of them is animal meat and bone meal of which especially bone meal has high phosphorus concentrations. Public health problems (e.g. BSE) and the actions needed to tackle them have made this process less efficient in recent years. Although some meat and bone meal is incinerated and the ashes are used either as fertiliser, directly as a form of soil improver, or in phosphorus production, much of the phosphorus is simply wasted.

After the outbreak of the Creutzfeld-Jacob disease as a result of eating infected beef, the EU imposed more stringent regulations to stop this health risk. They included a ban on meat and bone meal (MBM) in feed for ruminants, which was later extended to a ban on feeding processed animal based proteins to all farmed animals. Before the Bovine Spongiform Encephalopathy (BSE) affair 10% of the feed originated from MBM. Nowadays most MBM is combusted for energy purposes. Meat and bone meal was also a high quality protein component for feed, and has been largely replaced by soybean cake. Due to BSE regulation about 16 Mton of MBM feed in the EU was replaced by an equivalent of 23 Mton soybeans, which has led to a large increase in soybean area in Brazil was one of the drivers for deforestation (Elferink *et al.,* 2007). According to Rodehutscord *et al.* (2002) the ban on meat and bone meal has led to an increase of inorganic feed phosphate of about 50 kton P in the EU-15, which is mainly derived from mining of rock phosphate.

It may be possible to refine the legal framework governing the uses of such material if other safe uses are identified. The European Commission is currently discussing options to amend EU legislation to allow the feeding of processed animal protein derived from non-ruminants (other than fish) to non-ruminants of a different species. This would imply that meat and bone meal from pigs could be fed to poultry and vice versa. For this option we therefore assessed the potential amount of soybean meal and inorganic feed phosphate that can be saved if MBM would be allowed in the pig and poultry sectors.

Parameterisation

Rodehutscord *et al.* (2002) estimated the production of meat and bone meal at 3000 kton and 1500 kton of animal fats for the EU-15 in 1999. The average fraction of MBM in animal industrial feed was 2.9%. For the EU-15 the potential amount of MBM was calculated, for poultry this would be 1115 kton and for pigs 851 kton (Rodehutscord *et al.,* 2002). Based on the carcass ratio the amount of animal waste products was calculated by MITERRA-Europe. The total amount of animal waste and by-products in NW Europe is estimated at 3000 kton for pigs and 1675 kton for poultry. We assumed that about a third of this amount can be used for the production of meat and bone meal, based on the MBM production in the EU-15 before 2000 (Rodehutscord *et al.,* 2002). The remaining part is used for industrial purposes or not suitable for MBM. This results in a potential amount of about 1000 kton MBM from pigs and 550 kton from poultry for NW Europe.

Based on Miller & De Boer (1988) the average maximum amount of MBM in the animal diet was set at 5% for poultry and 4% for pigs (Table 5). However, according to Rodehutscord *et al.* (2002) the maximum values are lower, about 2.5% for both animal types. For ruminants the proposed update of EU legislation does not allow consumption of meat and bone meal. The total feed intake by pigs in NW Europe is about 43.1 Mton and for poultry 17.2 Mton (in dry matter). For pigs the amount of 550 kton MBM could be used in the feed, since this is about 1.3% of the total feed intake. For poultry the amount of 1000 kton MBM is 5.8% of the feed intake, which is too high. Using a maximum of 5% of the feed intake the potential amount of MBM would be 860 kton.

Rodehutscord *et al.* (2002) assumed a ratio of animal meal : bone meal of 0.34:0.66, this is based on the general feed practice in Germany. Based on this ratio and the data in Table 6, the average N content of MBM was set at 80 g/kg and the P content at 50 g/kg. The N content of soybean cake is about 72 g/kg, which means that 1 ton MBM can replace 1.11 ton soybean meal. Since the P content of MBM is much higher compared to soybean cake (P content of 7 g/kg), the additional amount of P from MBM can replace inorganic feed phosphates.

Table 5. Indicative maximum rates of animal by-products in animal diets (% of inclusion) of the rendering industry for different animal types and life stages, based on data of trade experience (Miller & De Boer, 1988)

Diet	Meat and bone meal	Feather meal	Blood meal	Poultry by-product meal
Poultry				
Chick	2.5 – 5	2	2	2 – 2.5
Grower	5	2	2	2 – 5
Layer	6	2	2	2 – 5
Breeder	5	2	2	0
Broiler starter	3 - 6	1	1	2 – 2.5
Turkey starter	3	2	2	0
Turkey grower	5	2	2	5
Turkey finisher	5	2	2	5
Duck starter	5	2	2	2
Duck finisher	5	2	2	4 – 5
Pig				
Weaner 20 kg	0 - 5	0	0	0
Grower 20-50 kg	2.5 - 5	0 – 1	0	0 – 2.5
Finisher >50 kg	4 - 5	0 – 2	2.5	0 – 2.5
Sows	4 - 5	0 – 2	2.5	0 – 2.5
Ruminant				
Calf	0	0	0	0
Dairy	2.5 - 5	2.5 – 5	2.5	2.5 – 5
Beef	5	2.5 – 5	2.5	2.5 – 5
Sheep, goat	5	2.5 – 5	2.5	0 – 5
Fish				
Salmon, trout	15	5	2	15
Carp	18	5	2	18 – 20

Table 6. Properties of meat and bone meal (MBM) for dry matter (DM), N and P content in g/kg

Type of meat and bone meal	DM	N	P	Reference
Defatted meat and bone meal	930	88	52	Sellier (2003)
Meat and bone meal	950	86	48	Sellier (2003)
Cattle	957	95	27	Karakas *et al.* (2001)
Cattle	959	85	45	Karakas *et al.* (2001)
Cattle	961	75	64	Karakas *et al.* (2001)
Pigs	978	107	29	Karakas *et al.* (2001)
Pigs	984	94	50	Karakas *et al.* (2001)
Pigs	983	71	80	Karakas *et al.* (2001)
Meat and bone meal		84	44	Garcia and Rosentrater (2008)
Meat and bone meal		81	51	Garcia and Rosentrater (2008)
Meat and bone meal			32	Garcia and Rosentrater (2008)
Meat and bone meal	970	79	56	Jeng *et al.* (2006)
Meat and bone meal	978	92	47	Jeng *et al.* (2006)
Animal Meal	950	87	31	Rodehutscord *et al.* (2002)
Bone Meal	940	65	61	Rodehutscord *et al.* (2002)

Results
Based on the parameterisation described above, the potential amount of MBM for animal feed for both pigs and poultry is 1410 kton (FM). This could reduce the total soybean cake consumption by 1570 kton, which is about 11 kton P (assuming a P content of 7 g/kg). Since the P content of MBM is higher compared to soybean also the amount of P from inorganic feed phosphates can be reduced. Based on the available data the average P content of meat and bone meal was set at 50 g P/kg. The amount of 1410 kton MBM contains 70.5 kton P, thus IFP can be reduced by 59.5 kton (70.5 minus 11 kton P).

3.3 Summary and discussion of results for Northwest Europe

In this chapter we summarised the results of the five options for reducing P losses from the P cycle in agriculture. Table 7 shows the soil P balance, the soil P surplus and the crop P use efficiency for the different options. The crop P use efficiency is defined as the crop uptake divided by the inputs (P from mineral fertiliser, applied manure, grazing manure, deposition, compost and sewage sludge). The results show that the overall P use efficiency ranges between 71% and 77% for the different options. Reducing mineral fertiliser use decreased the soil P surplus most, followed by reduced P excretion. Recycling of organic waste and replacement of soybean and IFP by meat and bone meal have no effect on the soil P surplus.

Table 8 shows the animal P balance and the animal P use efficiency for the different options. The animal P use efficiency is defined as the final animal product divided by the inputs (local feed, imported feed and inorganic feed phosphate). The results show that the overall P use efficiency is rather low with 17-18%. However, a large part of the P output is manure, which is internally recycled within the system, thus at farm level the P use efficiency is much higher. The option of reduced P excretion increases the animal P efficiency most, while the reduction of mineral fertiliser use and the use of organic waste have no effect on the animal P balance.

Table 7. Summary of resulting agricultural P inputs and soil P balances (in kton P) in NW Europe for the 2004 reference situation and the five options

	Reference 2004	Reduced mineral fertiliser use	Reduced P excretion	Use of organic waste	No export of animal products outside NW Europe	Replacement of soybean and IFP by MBM
Mineral fertiliser	614	488	614	528	614	614
Applied manure	631	631	546	631	556	631
Grazing manure	334	334	309	334	316	334
Deposition	18	18	18	18	18	18
Compost	6	6	6	26	6	6
Sludge	73	73	73	139	73	73
Crop uptake	1191	1191	1191	1191	1191	1191
Soil P surplus	485	359	375	485	392	485
Crop P use efficiency (%)	**71%**	**77%**	**76%**	**71%**	**75%**	**71%**

Table 8. Summary of resulting animal P balance (in kton P) for the livestock sector in NW Europe for the 2004 reference situation and the five options

	Reference 2004	Reduced mineral fertiliser use	Reduced P excretion	Use of organic waste	No export of animal products outside NW Europe	Replacement of soybean and IFP by MBM
Local feed	1059	1059	1059	1059	982	1070
Imported feed	135	135	110	135	68	124
Inorganic feed phosphate	132	132	66	132	66	73
Animal products	231	231	231	231	195	231
Animal waste	20	20	20	20	18	20
Excretion	954	954	838	954	856	954
Animal P use efficiency (%)	**17.4%**	**17.4%**	**18.7%**	**17.4%**	**17.5%**	**18.2%**

In principal all five options that were assessed can be combined, although for some options there can be some double counting, e.g. reduced P excretion will lower the potential for reduced mineral fertiliser use. We did not calculate the combined effect of all options together, but the summation of the reductions in P input of the different options and the resulting soil P balance are shown in Table 9. This shows that the soil P surplus could theoretically decrease from 954 kton P to 154 kton P.

Although the soil P balance and the animal P balance provide useful information, they do not provide directly a clear picture on the total P cycle in agriculture. A closed P cycle in agriculture should theoretically not require external inputs such as mineral P fertiliser and inorganic feed phosphate that are presently based on mineral P mined as phosphate rock. In contrast to nitrogen, the P losses could be very small, since there are no gaseous emissions and P leaching only occurs in P saturated soils with high precipitation or groundwater level. Figure 7 shows the external P inputs, which consist of mineral fertiliser, imported feed from outside the EU and inorganic feed phosphate, for the 2004 reference and the different options. The total external P in NW Europe was 882 kton P in 2004. Reduced mineral fertiliser use and no export of animal products outside NW Europe have the largest reduction in external P inputs. When all options are combined the external P input to agriculture in NW Europe could be reduced by 50%. This replacement potential is relatively low since the options assessed are in most cases close to maximum achievable targets.

Table 9. Reduction in soil P balance inputs and outputs (negative numbers are increases), and the overall soil P balance (in kton P) for all options implemented together.

	Reduced mineral fertiliser use	Reduce P excretion	Use of organic waste	No export of animal products outside NW Europe	Replacement of soybean and IFP by MBM	Sum of combined options
Mineral fertiliser	126	0	86	0	0	402
Applied manure	0	85	0	75	0	471
Grazing	0	25	0	19	0	291
Deposition	0	0	0	0	0	18
Compost	0	0	-21	0	0	26
Sludge	0	0	-65	0	0	139
Crop uptake	0	0	0	0	0	1191
Soil P surplus	126	110	0	93	0	156

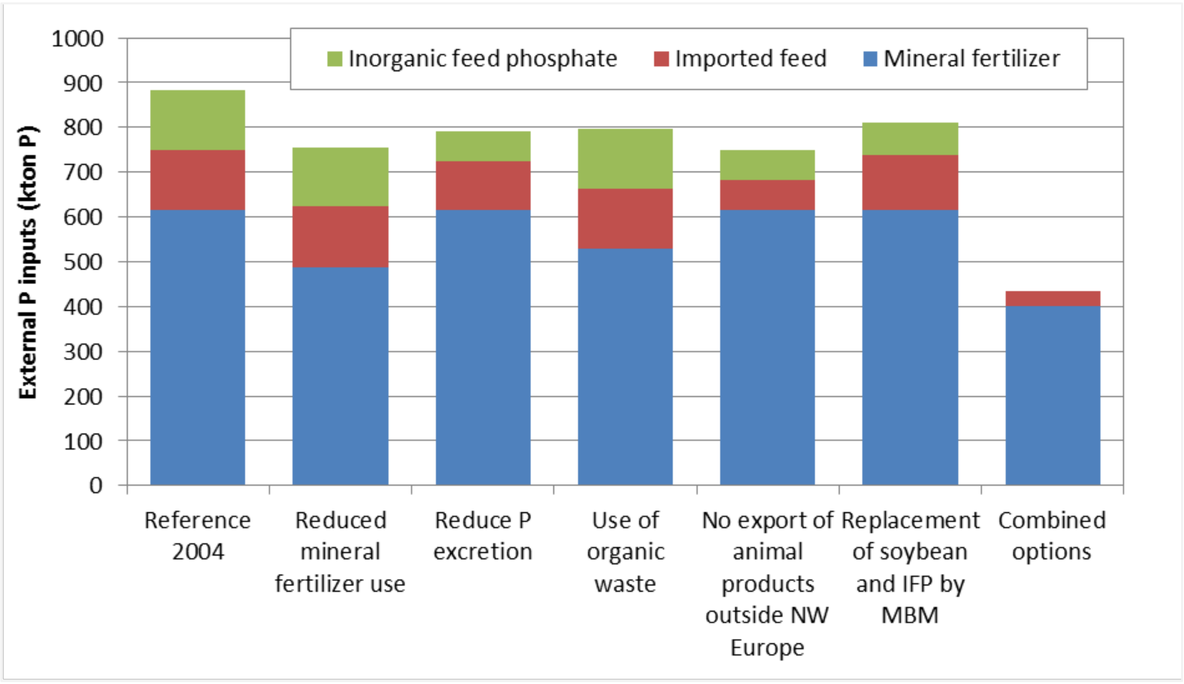

Figure 7. External P inputs to the agricultural system of NW Europe for the different options

4 Assessment for the Netherlands

4.1 Description of reference situation

Agriculture in the Netherlands is very intensive with high livestock densities and high crop and livestock productivities. On average the Netherlands has one of highest livestock densities in the world, with large numbers of dairy cattle, pigs and poultry (Table 10). Livestock densities are highest in Noord-Brabant and the Gelderse Vallei, where many high-intensive pig and poultry are located (Figure 8). The large concentration of livestock lead to high inputs of nutrients to grassland and arable land. As a consequence crop and grassland yields are very high, but also losses to the environment are high. Eutrophication of groundwater and surface water with nitrates and phosphates and nitrogen emissions to the air (mainly ammonia and nitrous oxide) have led to strict environmental legislation to prevent further pollution. In Lesschen *et al.* (2011b) the nitrogen emissions have been further quantified for 2009.

Table 10. Livestock numbers (x 1000) in the Netherlands per province (based on 2009 data)

Province	Dairy cattle*	Beef cattle	Beef calves	Pigs	Poultry	Other animals
Groningen	166	11	19	111	5392	61
Friesland	486	19	38	56	8785	153
Drenthe	175	18	29	164	6437	54
Overijssel	446	53	137	966	10460	111
Flevoland	51	2	10	41	2284	18
Gelderland	431	75	405	1313	18620	314
Utrecht	147	16	42	187	1944	60
Noord-Holland	140	17	2	12	1061	114
Zuid-Holland	166	20	6	88	698	112
Zeeland	33	15	3	48	1819	58
Noord-Brabant	404	67	189	3175	27296	652
Limburg	92	31	21	991	16446	205
Total	2738	344	901	7153	101241	1912

** Incl. young cattle*

Since this report is about phosphorus, we have described the reference situation for 2009 in more detail. The total P excretion by livestock was 76.3 kton P, of which most was coming from dairy cattle (46%), followed by pigs (26%) and poultry (17%), see Figure 9. From this amount 10.2 kton P was directly excreted on the field during grazing. About 22.5 kton P was exported or treated and removed from the Dutch agriculture. The remaining 42.6 kton P was applied on arable land and grassland. The total P input from mineral fertilizer was very low in 2009, with only 4.4 million kg P. In the period 2000-2008 the average P input was about 20 million kg. One of the reasons for the low mineral P fertilizer use was the high price during 2008-2009, but also the more strict manure policy in the Netherlands resulted in a decrease over the last decade.

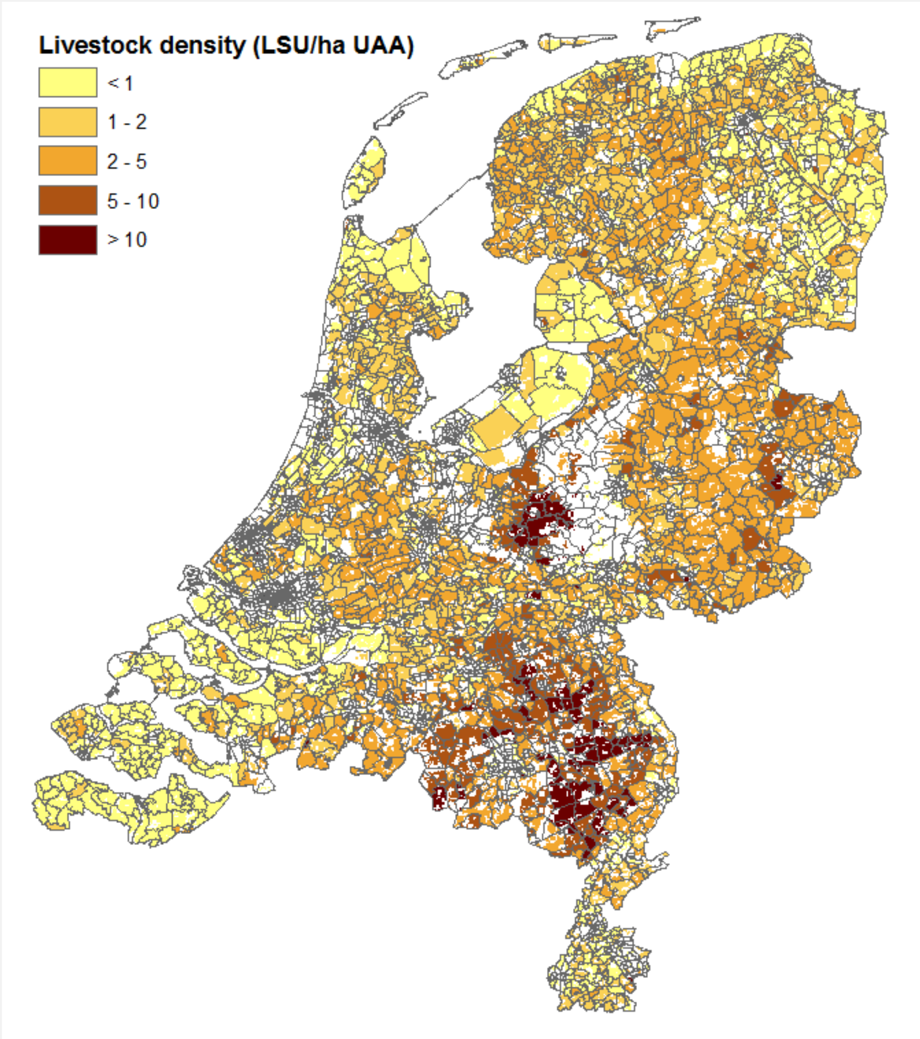

Figure 8. Distribution of the livestock density in the Netherlands in 2009

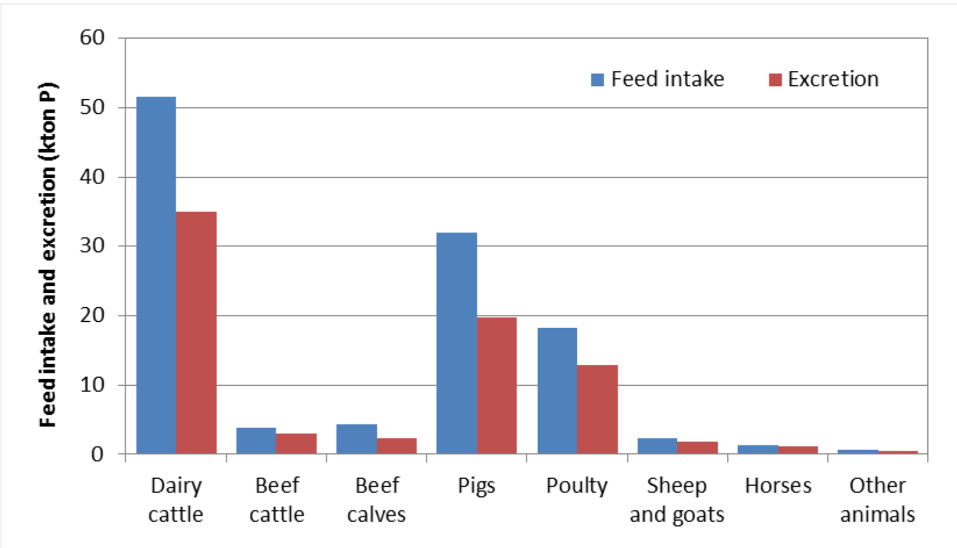

Figure 9. Total feed intake and excretion of phosphorus for different animal categories

In Figure 10 also the spatial distribution of these P inputs from manure, grazing and mineral fertilizer are shown. Mineral fertilizer input is nowadays mainly used on arable land, which is clearly shown in the Figure with highest inputs in Flevoland and Zeeland. Manure application is highest in the northern provinces, as there the P status of the soil is on average lower (see Figure 2) and therefore more space for manure application is available. P crop uptake is highest on grassland, which is clearly shown in Figure 11, with the highest P uptake in Friesland and the 'veenweide' regions. The net soil P surplus is on average in the range of 2-5 kg P, with highest surpluses in regions where arable crops dominate (Veenkoloniën, Flevoland, Noord-Holland and Zeeland). However, these surpluses are calculated by the model, based on the available statistics and the maximum application amounts from the manure legislation. This might differ from reality, where application limits are sometimes breached, especially in regions with high manure surpluses.

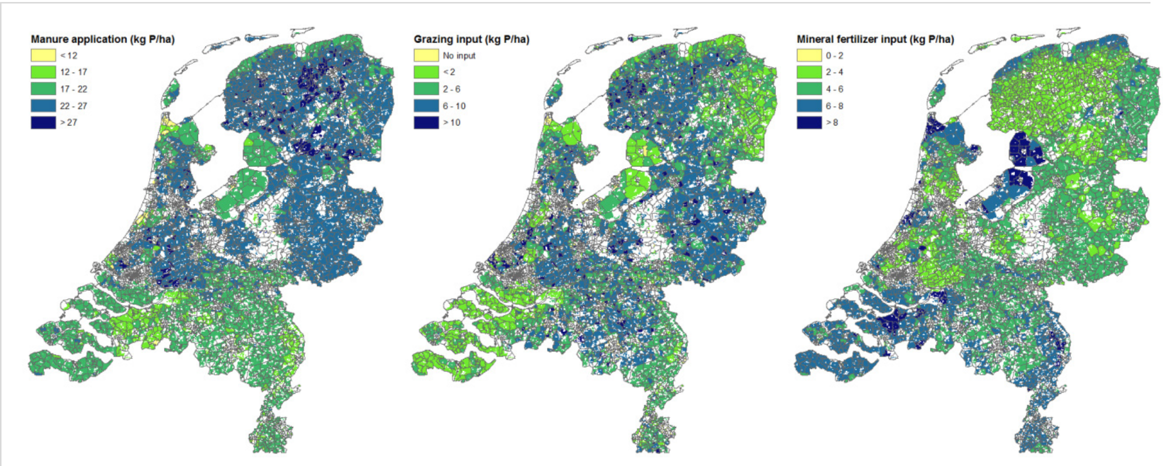

Figure 10. Distribution of P input from manure application (left), grazing (middle) and mineral fertilizer (right)

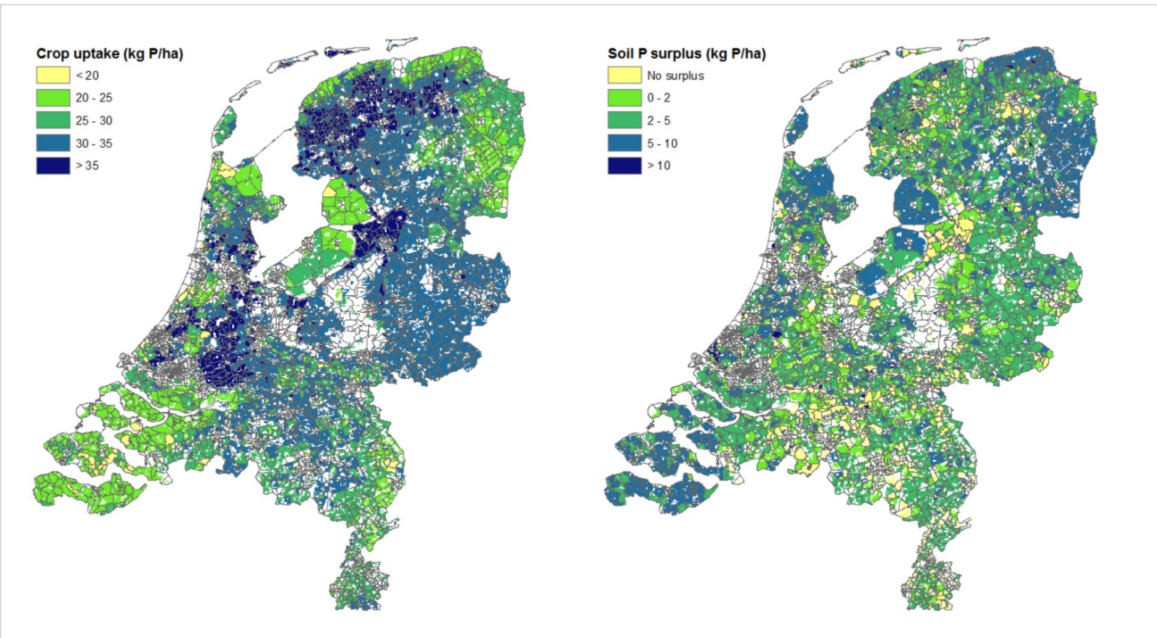

Figure 11. Distribution of the P crop uptake (left) and the soil P surplus (right) in the Netherlands

4.2 Options for reducing P losses

For the Netherlands the following options were included:

1. Reduction of P excretion: lower input of manure due to reduced feed P intake.
2. Maximum replacement of mineral fertiliser by P in waste streams: organic residues can be used as compost instead of fertiliser.
3. Reduction of manure and fertiliser application using balanced fertilisation: on basis of the amount of P which is harvested with the crop, we calculated the actual P amount needed.
4. Replacement of soymeal and inorganic feed phosphates by meat and bone meal.
5. Production of feed from biorefinery of grass; in the Netherlands there is a surplus of grass. After refining the grass, the protein component can be used in feed concentrates.
6. Self-sufficiency for animal products at national scale; in this option the number of animals is reduced to the level that would be needed to feed the entire Dutch human population. Consequently this means no export and a reduction of the animal number.
7. Large scale manure treatment; as a result of large scale manure treatment, based on separation of the solid and liquid fraction, more manure can be applied in the Netherland and manure export will be reduced.

4.2.1 Reduction of P excretion

Introduction

Over the last years the use of mineral P fertiliser has decreased drastically in the Netherlands from 33 million kg P in 1990 to 4.4 million kg P in 2009. However, the year 2009 was rather exceptional due to very high fertiliser prices and in 2010 the consumption has increased again. Still the three year average of 2008 – 2010 is much lower with 10.0 million kg P. however, the 2009 value was used as a reference for the mineral P fertiliser use. As the input of mineral P fertiliser is already low, a further reduction of the P input to the soil should come from a lower application from manure linked to feed P input. A possibility would be to reduce the feed P intake, which consequently results in a lower P excretion and a lower absolute input to the soil. A further reduction of manure P application can be realised by increasing the availability of P for the animal. This enhancement can increase the uptake of P by the animal during digestion directing P towards the animal products or slaughter wastes.

The technical cost-effective potential for reducing P excretion is estimated at 20% (Van Krimpen *et al.,* 2010). However, there is no incentive yet for farmers to do this, since there is not an accounting system based on P content, and costs savings are small, because intensive pig and poultry farms have to export nearly all manure from their farms. According to Kortstee *et al.* (2011) such a reduction should be possible using different feeding measures without increasing costs. Possible measures are changes in the feed composition (e.g. less soybean), reduced use of inorganic feed phosphate (IFP) and increased use of phytase, which increases the P availability in feed. However, livestock farmers and veterinarians are concerned that feedstock reduced in phosphate may negatively affect animal welfare. Phosphate requirements of animals depend on the animal species, it's physiological status, and the availability of the P forms in the feed. Also conditional requirements such as the duration of the growth phase effects P requirements.

Parameterisation

For this option we simulated the effect of a lower P excretion according to Lesschen *et al.* (2011b). In that study scenarios for large scale manure treatment were assessed, including several scenarios with reduced N and P excretion, i.e. 10% lower N excretion and 20% lower P excretion. For this option the lower excretion rates are assumed for cattle and pigs using data from the reference year 2009. We assumed three pathways to reduce P excretion. Firstly the P intake of IFP was reduced, which accounts for 30% of the reduction in P excretion. Secondly the composition of concentrate feed is changed, which accounts for 50% of the reduction in P excretion. In this case we assumed less soybean materials in the concentrate feed, which consequently reduced the import of soybean. Finally, 20% of the reduction in P excretion is due to a lower P content in the roughage intake (e.g. through lower P fertilisation).

Results

The lower excretion rates result in a reduction of 13% of the soil P input from grazing and manure application and a reduction of 18% of P in exported manure. The reduction in exported pig manure is larger, since more manure can be applied within the limits of the different fertilisation standards. Nevertheless, a large part of the export consists of poultry manure, for which no reduction in P excretion is assumed. In a recent study De Buck *et al.* (2012) also calculated the effect of a reduction in P excretion through feed concentrates with lower P content for the year 2008. Using feed concentrates 10% lower in P for dairy cattle and intensive livestock resulted in a decrease of the national P surplus of 2 and 5 kton P respectively. This is in line with our calculations showing a reduction of the P surplus by 7 kton P. Additionally the export of manure can be lowered by 4 kton P.

4.2.2 Maximum replacement of mineral fertiliser by waste streams

Introduction

For the Netherlands this option has only limited potential since the use of mineral P fertiliser has decreased drastically over the last years. In 2009 the phosphate use was only 4.4 million kg P, which is not expected to reduce much more on the short term, as crops with a short growing period and a high daily phosphate demand will – especially at a lower soil P status – benefit from fertilisation with mineral P fertilisers. Also some specialised crops in the horticulture sector need mineral fertiliser instead of manure. Still we made an assessment of the potential amount of organic residues that could be used as compost.

Parameterisation and results

According to Milieu Ltd *et al.* (2009) about 2.45 million ton of biowaste and green waste can potential be collected for composting in the Netherlands. In 2005 already 1.66 million ton is separately collected and used for composting. Using the nutrient contents of Van Dijk & Van Geel (2010), see Table 11, this represent a total amount of 2.06 kton P. In the Netherlands on average 55% of the produced compost is used in agriculture and horticulture (Werkgroep Afvalregistratie, 2009). Assuming a similar ratio between biowaste and green compost, the potential additional amount of compost that could be used in agriculture would be 0.8 million ton, which is about 1.0 kton P.

Table 11. Properties of compost in kg per ton fresh matter based on Van Dijk & Van Geel (2010)

	DM	OM	N total	P_2O_5	K_2O
Biowaste compost	650	190	8.5	3.7	6.4
Champost	350	220	5.8	3.6	8.7
Green compost	598	186	5.1	2.2	4.2

Sewage sludge contains many nutrients and is in some countries a significant source of nutrient input. However, the use of sewage sludge on agricultural land is not allowed in the Netherlands, because of environmental (e.g. heavy metals) and sanitary (e.g. antibiotics and organic micro pollutants) reasons. The estimated amount of sewage sludge produced in the Netherlands is 550 kton dry matter, based on Milieu Ltd. *et al.* (2009). This represents an amount of 18.1 kton of P. This is in line with the amounts estimated by Smit *et al.* (2010).

Although direct use is not allowed since 1995, P can also be recovered from sewage sludge to produce mineral P fertilisers. Several initiatives are currently carried out to recover phosphate. These processes include struvite and dicalciumphosphate production from wastewater treatment plants and phosphate recovery from ashes after incineration of composted sewage sludge. These initiatives are not yet applied at large scale, but in the 'chain agreement' that was signed in 2011, there is the intention to build several large scale installations that can recycle the P from sewage sludge. However, on the shorter time scale (2015) we assume that only 10% of the P in sewage sludge can be recovered and replace mineral fertiliser, this would be 1.8 kton of P. The sum of the additional amount of compost and the recovered P from sewage sludge could reduce the P fertiliser use by 2.8 kton of P.

4.2.3 Reduce manure and fertiliser application using balanced fertilisation

Introduction

Phosphate is and has been accumulating in the soils in the Netherlands due to high inputs of manure and to lesser extent mineral fertiliser (Figure 12). The balance between input of P to the soil, the uptake by agricultural crops and the losses by leaching needs to be improved. Most soils in the Netherlands have already a high phosphate status (see Figure 2), which means that over fertilisation is not required and even under fertilisation can be applied in soils with a high P status (soil P mining). For this options we calculated therefore the amount of required P fertiliser using the principle of balanced fertilisation.

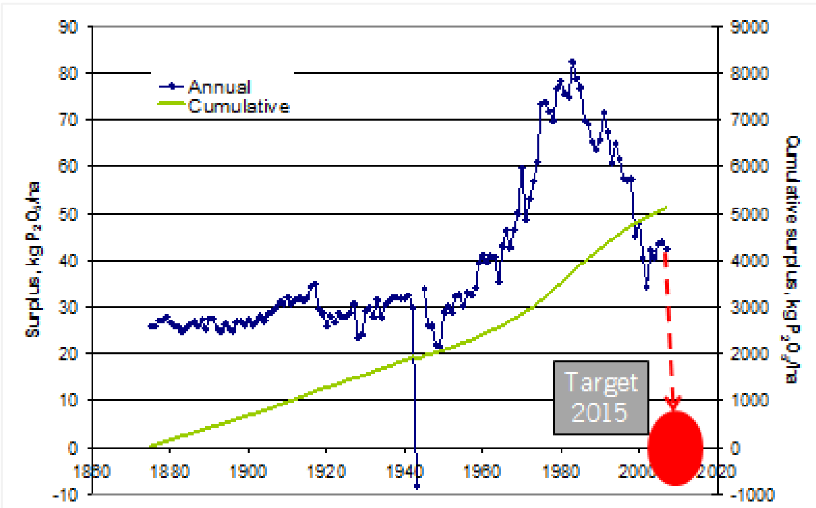

Figure 12. Average phosphate surplus in Dutch agriculture from 1880-2010 (Ehlert, unpublished)

Parameterisation and results

MITERRA-NL calculates the P demand, based on crop yields and the P content of the crop, which is derived from Ehlert *et al.* (2009). According to calculations with MITERRA-NL (see Lesschen *et al.*, 2011b), based on the fertilisation standards of 2009, there would be space for 79.6 kton of P on the agricultural soils in the Netherlands. However, using the expected future application standards for 2015, which are more strict, only 62.7 kton of P can be applied. However, the current P crop uptake is lower and estimated at 56.9 kton of P. Thus using a strict balanced fertilisation approach would allow a maximum input of 56.9 kton P by mineral fertiliser, manure and other organic inputs. For the reference situation in 2009 the total input is 58.3 kton P, thus still a reduction of 1.4 kton is needed. The total mineral P fertiliser use is 4.4 kton P, thus by reducing this input the criteria of balanced fertilisation would be complied. Nevertheless, a further reduction could be possible since a large part of the agricultural soils are saturated with P due to large surpluses over the last decennia. However, since mineral fertiliser use has been decreased over the last years, a further reduction should come from a reduction in the amount of manure P. The question is then what to do with the manure surplus: more export, less animals or manure treatment? The current policy proposals chose for more manure treatment and export of the treated manure P.

4.2.4 Replace soymeal and feed phosphate by meat and bone meal

Introduction

After the outbreak of the Creutzfeld-Jacob disease as a result of eating infected beef, the EU imposed more stringent regulations to stop this health risk. This included a ban on meat and bone meal (MBM) in feed for ruminants, which was later extended to a ban on feeding processed animal based proteins to all farmed animals. After the ban on MBM the use of soybean cake, wheat and maize considerably increased. Also the use of phytase, which increases the P availability in feed, increased. In addition, the use of IFP (often mono calcium-phosphate) increased, especially for laying hens, which have a calcium and phosphate requirements (Veldkamp *et al.*, 2010).

The European Commission is currently discussing options to amend EU rules to allow the feeding of processed animal protein derived from non-ruminants (other than fish) to non-ruminants of a different species. This would imply that meat and bone meal from pigs could be fed to poultry and vice versa. For this option we therefore assessed to potential amount of soybean meal and IFP that can be saved if MBM would be allowed in the pig and poultry sectors.

Parameterisation

From the CBS feed data it is not clear which part of the concentrate feed consist of soybean. Based on NEVIDI data the proportion of soybean meal in the total concentrate feed is 11%. On the basis of MITERRA-Europe / CAPRI data the share of soybean in protein rich feed for the Dutch livestock sector is 61%. If the share of soybean is the same for all animal categories, the current soybean consumption by pigs is than 965 kton (DM) and for poultry 333 kton, which could in principal be replaced by MBM. The further parameterisation and assumptions of this option are the same as used for NW Europe (see Section 3.2.5).

Results

The total feed intake by pigs in the Netherlands is about 4.93 Mton and for poultry 1.28 Mton (in dry matter). For pigs the amount of 63 kton MBM could be used in the feed, since this is about 1.3% of the total feed intake. For poultry the amount of 140 kton MBM is almost 11% of the feed intake, which is too high. Using a maximum of 5% of the feed intake, the potential amount of MBM would be 64 kton. The total soybean cake consumption could therefore be reduced by 127 kton, which is about 0.89 kton P (assuming a P content of 7 g/kg). Since the P content of MBM is higher compared to soybean also the amount of P from IFP can be reduced. Based on the available data from Table 6, the average P content of meat and bone meal was set at 50 g P / kg. The amount of 127 kton MBM contains 6.35 kton P, thus IFP can be reduced by 5.46 kton.

4.2.5 Production of feed from grass refinery

Introduction

The Netherlands has a surplus of grass due to more extensive farming enforced by manure legislation as well as the expanding area of (natural) grassland. With grass refinery more value could be added to the growing surplus of grass. Refining grass aims to isolate the low-grade grass protein and then upgrade it for use in feed concentrates. The residual fibre must also be put to profitable use, for example as an ingredient for the paper-making industry or as a co-product for biogas production. Grass refining can thus help to make livestock farming more sustainable, while creating new economic prospects for grass cultivation. Schouwmans *et al.* (2010) expect that biorefinery could reduce the total import of P by 1 to 5 million kg per year.

Currently some pilot studies (e.g. GRASSA) are on-going which confirm the possibility of making large scale grass refinery profitable[1]. The potential amount of surplus grass in the Netherlands is estimated at 2 million ton FM per year. From this amount about 75 kton protein (dry matter) can be extracted (Carel de Vries, Courage, Zoetermeer; pers. com.). This could halve the soymeal consumption in the Dutch dairy sector. Although this potential is uncertain, recent studies show that also other biomass sources could be used, e.g. sugar beet leaves and residues from greenhouses. Therefore we assumed that the amount of 75 kton of protein from grass refinery should be possible.

Parameterisation and results
We assumed that this amount will be proportionally used in concentrate feed over the sectors, i.e. 25% for cattle, 44% for pigs and 27% for poultry (based on data from NEVIDI). The 75 kton of protein is equal to 167 kton soybean meal, which contains about 1.17 kton P (P content is 7 g/kg), this is in line with the estimate of Schoumans *et al.* (2010). The amount of P from the refined grass in the animal feed is not yet known. The P content of fresh grass is 3.8 g/kg, which is about 19 g/kg based on DM. This is higher compared to the soybean meal, but probably most of the phosphorus is not in the protein part. Therefore we assumed that the net P intake does not change when soybean meal is replaced by feed from grass refinery. The net effect of this option is thus a shift of 1.17 kton P from imported feed to local feed. Overall this is a small but effective contribution to close feed-manure cycles at national scale.

4.2.6 No export of animal products outside the Netherlands

Introduction
One of the main options to close the feed manure cycle is to match livestock production with the demand for livestock products in a certain region. The Netherlands has a very intensive livestock production and for most livestock products the production is (much) higher than the consumption, which means that part of the livestock sector is producing for export markets. In this option the number of animals is reduced to the level that would be needed to feed the entire human population of the Netherlands and no longer produce animal products for export.

Parameterisation
In this option the number of animals is reduced to the level that would be needed to feed the entire Dutch human population and no longer produce animal products for export. Based on the food balance sheet data from FAOSTAT the level of overproduction was calculated, which was converted to a reduction in animal numbers (Table 12). For all livestock products the Netherlands produces more than is needed for own consumption. The relative reduction in livestock numbers was equally spread over the Netherlands. Based on these reductions, MITERRA-NL was run, with reduced number of animals, feed intake and livestock products. All other parameters, e.g. land use, remained the same, which is an oversimplification, as in reality land used for fodder production might be converted to other crops. For the reduction in animal feed we assumed that the proportional decrease is stronger for imported feed and inorganic feed phosphate, since local feed production will remain.

[1] http://www.groenegrondstoffen.nl/downloads/Infosheets/Pilot%20grasraffinage.pdf
http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/Presentatie__7__Grasraffinage_Courage_WS_061207.pdf
http://www.courage2025.nl/courage_project_Grasraffinage.html

Table 12. Animal product production, consumption, overproduction and reduction in livestock numbers for the option of self- sufficiency in the Netherlands

Animal product	**Production**	**Consumption**	**Overproduction**	**Reduction livestock numbers**
	kton	kton	%	%
Bovine meat	396	262	51	34
Pig meat	1297	580	124	55
Poultry meat	692	334	107	52
Mutton and Goat Meat	14	13	8	7
Milk	10847	5635	36*	27
Eggs	607	286	112	53

* The overproduction for milk is less compared to the consumption, since additional to the human consumption 2323 kton milk is used for animal feeding

Results

The reduction in livestock animals has a very strong effect with a reduction of 38% in the total P excretion. This reduction results in a 30% decrease in grazing and applied manure, which leads to a negative soil P balance. However, the negative balance should be treated with care, because no change in crop uptake is assumed. Whereas in reality crop production will decrease or change, this holds especially for grasslands. The export and treatment of manure decreases almost by 60% to 9.4 kton P. This export could even reduce further, as there would be space left for manure application, but we kept the current export of poultry manure constant.

4.2.7 Large scale manure treatment

Introduction

Beside changes in feeding practices and export of manure, treatment of manure is considered as a possibility to increase the efficient use of nutrients in manure. One possible way of treatment is that livestock liquid manure is separated and that the mineral concentrate, which results from reverse osmosis of the liquid fraction, is used as a mineral N and K fertiliser. In a pilot study the agricultural, economic and environmental impacts of production and use of mineral concentrates as mineral fertilisers were assessed (Velthof, 2012). However, large scale implementation of these high-tech slurry separation techniques is not yet expected, whereas low tech slurry separation (mechanical, e.g. *vijzelpers*) are expected to be more widely used because of lower investment costs. In Lesschen *et al*. (2011b) a series of scenarios of large scale manure treatment were assessed. The production and large scale use of mineral concentrate in the Netherlands will lead to a decrease in the need for both mineral P fertiliser (up to 82%) and N fertiliser (up to 15%). The decrease in P fertiliser is mainly due to more efficient use of the solid fraction after manure treatment, which results in lower exports. Based on this study we defined one scenario that can be considered as a realistic option, given the current policy debate. In September 2011 the ministry proposed that all surplus manure should be either treated at certified installations, exported or used at by other farmers with guaranteed contracts.

Parameterisation

For this option we made the following assumptions. Slurry will be separated with low tech options into a thick and a thin fraction. Since most pig-farmers have no or insufficient land there will be a higher need for manure treatment, hence we assume that 30% of all pig manure will be treated. For cattle manure the percentage will be lower, since they have more land available, therefore we assume that 10% will be treated. The manure and application standards for 2009 were used in the calculation.

Results

As a result of this large scale manure treatment, more manure can be applied in the Netherlands and the export of manure reduces with 1.8 kton P (8% reduction). However, the export of pig slurry decreases much more by 46%. The additional amount of P manure that can be applied could replace mineral P fertiliser as well. However, since the application rate of mineral P fertiliser is already rather low, a further reduction is not expected, since the current application standards do allow for higher application rates. From another perspective, with more stringent P application standards that will be implemented from 2014, there will be no longer space for additional P application, which means that manure treatment will only increase the export of manure.

4.3 Summary and discussion of results for the Netherlands

In this chapter we summarised the results of the seven options for reducing phosphorus losses from the P cycle in agriculture in the Netherlands. Table 13 shows the soil P balance, the soil P surplus, the manure export and the crop P use efficiency for the different options. The crop P use efficiency is defined as the crop uptake divided by the inputs (mineral fertiliser, applied manure, grazing manure, compost and sludge). The results show that the overall P use efficiency ranges between 95% and 134%. These efficiencies seem very high, however, inputs of especially mineral P fertiliser have been drastically decreased during the last years, and over the last decades a very large P surplus has accumulated in the Dutch agricultural soils.

Furthermore, crop uptake has been kept constant for all options. In case of small reductions (<10%) of the total P input no crop response is to be expected, since a large part of the agricultural soils are saturated by phosphate. However, for the option in which the animal numbers are reduced at the level that no export will occur, the P input is drastically reduced and a crop response is to be expected. Furthermore also the crop distribution will change due to less demand for animal feed, e.g. conversion from fodder maize and grassland to food crops. In that case the crop uptake will be lower. Besides this extreme option, the reduction of P excretion is most effective in reducing the soil P surplus. Replacement of mineral P fertiliser, feed from grass refinery and replacement of soybean and IFP by MBM have no effect on the soil P surplus, while large scale manure treatment increases the soil P surplus.

Table 13. Summary of resulting agricultural P inputs and soil P balances (in kton P) in the Netherlands for the 2009 reference situation and the seven options

	Reference 2009	**Reduction P excretion**	**Replace mineral P fertiliser**	**Balanced fertilisation**	**No export of animal products**	**Feed from grass refinery**	**Use of meat and bone meal**	**Large scale manure treatment**
Mineral fertiliser	4.4	4.4	1.6	3.0	4.4	4.4	4.4	4.4
Grazing manure	10.2	8.5	10.2	10.2	7.8	10.2	10.2	10.2
Applied manure	42.6	37.3	42.6	42.6	29.2	42.6	42.6	44.4
Compost	1.1	1.1	2.1	1.1	1.1	1.1	1.1	1.1
Sludge	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0
Crop uptake	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9
Soil P surplus	1.4	-5.6	1.4	0.0	-14.5	1.4	1.4	3.2
Manure export	22.5	18.5	22.5	22.5	9.4	22.5	22.5	20.7
Crop P use efficiency (%)	**98**	**111**	**98**	**100**	**134**	**98**	**98**	**95**

Table 14 shows the animal P balance and the animal P use efficiency for the different options. The animal P use efficiency is defined as the final animal product divided by the inputs (local feed, imported feed and inorganic feed phosphate). The results show that the overall P use efficiency is about 22%, which is somewhat higher compared to the average of NW Europe, but much lower compared to the crop P use efficiency. However, a large part of the P output is manure, which is internally recycled within the system, thus at farm level the P use efficiency is much higher. Reduced P excretion increases the animal P efficiency most, while most other options have no effect.

Table 14. Summary of resulting animal P balance (in kton P) for the Dutch livestock sector for the 2009 reference situation and the seven options

	Reference 2009	**Reduction P excretion**	**Replace mineral P fertiliser**	**Balanced fertilisation**	**No export of animal products**	**Feed from grass refinery**	**Use of meat and bone meal**	**Large scale manure treatment**
Local Feed	67.2	64.8	67.2	67.2	48.5	68.3	73.5	67.2
Imported feed	39.8	33.8	39.8	39.8	18.2	38.7	38.9	39.8
Feed phosphate	7.0	3.4	7.0	7.0	3.5	7.0	1.6	7.0
Excretion	76.3	64.3	76.3	76.3	47.3	76.3	76.3	76.3
Animal products	24.7	24.7	24.7	24.7	16.2	24.7	24.7	24.7
Slaughter waste	13.3	13.3	13.3	13.3	6.7	13.3	13.3	13.3
Animal P use efficiency (%)	**21.7**	**24.2**	**21.7**	**21.7**	**23.1**	**21.7**	**21.7**	**21.7**

Ideally for a closed P cycle in agriculture, both the external inputs (mineral fertiliser imported feed and IFP) and the manure export and treatment should be close to zero. Figure 13 shows the amount of external P inputs to the agricultural system and the export of manure for the different options. The agricultural system comprises both the crop and livestock production in the Netherlands. The option of no export of animal products is in this respect the most effective option, with a reduction of the external inputs by 50% and a reduction of the manure export and treatment of almost 60%. Besides this option, the reduction in P excretion is most effective.

Most of the options can be applied in combination, although, the option of balanced fertilisation might overlap with the reduction of P excretion. The option no export of animal products requires a very strong shrinkage of the Dutch livestock sector with reductions in animal numbers up to 50%. This is not considered as a realistic scenario on the short term, and therefore this option was not included in the combined effect of all options together. Combining the other six options resulted in a total external P input of 32 kton P, which is a reduction of 35% compared to the 2009 reference, and a reduction of the manure export and treatment by 26% to 16.7 kton P. The annual soil P balance would become slightly negative with -5.1 kton P, which is about -2.6 kg P/ha agricultural land. This is not a problem for crop productivity in most cases, since Dutch agricultural soils have on average a high P status (see Figure 2).

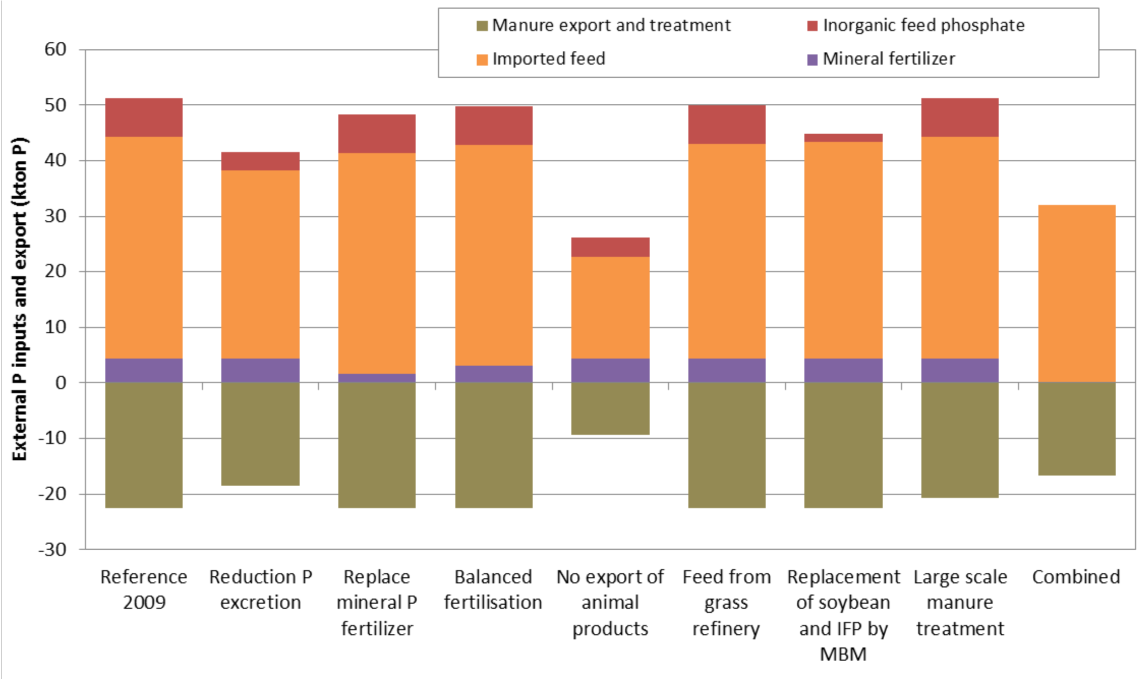

Figure 13. External P inputs to the agricultural system and manure export and treatment for the different options

5 Conclusions

In this study we designed and assessed five options to reduce P losses in agriculture for the NW Europe and seven options specific for the Netherlands. At both spatial scales the option of no export of animal products (100% self-sufficiency), with as a consequence the reduction in livestock numbers, is most effective in reducing external P inputs. However, this option has significant economic impacts, with on average a reduction in livestock numbers of 10% for NW Europe and at the national scale for the Netherlands even a reduction of almost 40%.

An effective option that is more easy to implement, probably without any cost or productivity effects, is the reduction in P excretion through changes in the feed intake. This option could reduce the soil P surplus in NW Europe by 23% and for the Netherlands reduce the import of feed from outside the EU by 15% and the export of P manure 18%. At NW European scale the reduction of mineral P fertiliser through balanced fertilisation is also an effective option, which can reduce the soil P surplus by 26% and increase the crop P use efficiency to 77%. In the Netherlands this option is less effective due to the already low P fertiliser inputs and the high inputs from manure.

Some of the measures do not directly improve the crop or animal P use efficiency, e.g. the maximum recycling of organic waste (i.e. biowaste, greenwaste and sludge) for use in agricultural systems or the production of feed from grass refinery, but these options do lower the demand for external P inputs and thus contribute to a more balanced feed-manure P cycle. The effect of large scale manure treatment in the Netherlands on the closure of the feed-manure P cycle is limited. Obligatory manure treatment is currently proposed as the alternative for the milk quota and animal production rights for the poultry and pig sector. Due to the lowering of the P application standard, no space is left for additional application of manure P within the Netherlands. This means that most of the P in treated manure is exported. If this manure P would be exported to the areas where feed is produced, the feed-manure P cycle would be more in balance at least at larger scale. However, it is not expected that manure will be exported outside the EU, e.g. to Brazil from where most of the soybean is imported.

A combination of different options will be most effective in reducing P losses from the feed-manure cycle. For NW Europe the combination of all five options can lead to a reduction of external P inputs of about 50%. For the Netherlands the combination of the six options, excluding the no export of animal products, will lead to a total external P input of 32 kton P, which is a reduction of 35% compared to the 2009 reference, and a reduction of the manure export and treatment by 26%.

However, a fully closed feed-manure P cycle will difficult to obtain on both NW European as well as national scale. For NW Europe the external input of mineral P fertilizer is most important, which cannot be completely replaced by manure and other organic inputs as sewage sludge and compost. In the Netherlands the import of feed from outside the EU is most important, whereas mineral P fertilizer has only a limited contribution, which can be replaced by other P inputs. Reduction of the imported feed quantity is possible, but a completely closed feed-manure P cycle is not possible without a large reduction in animal numbers.

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2012

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2013

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