Development and application of the integrated nitrogen model MITERRA-EUROPE

Task 1 Service contract "Integrated measures in agriculture to reduce ammonia emissions"

G.L. Velthof
D.A. Oudendag
O. Oenema

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Tenderer Consortium
Alterra, Wageningen UR, The Netherlands
EuroCare, University of Bonn, Germany
ASG, Wageningen UR, The Netherlands

Sub contractors
Umweltbundesamt, Austria
NEIKER, Spain
IMUZ, Poland
CEH, United Kingdom
MNP, Netherlands
ECN, Netherlands

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ABSTRACT

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The European Commission, Directorate-General Environment, has contracted a consortium led by Alterra (Wageningen University and Research Centre) for the Service Contract: "Integrated measures in agriculture to reduce ammonia emissions". The general objective of the contract was to have defined the most appropriate, integrated and consistent actions to reduce nitrogen emissions from agriculture to the atmosphere, groundwater and surface waters. Both ancillary benefits and trade-offs of measures had to be identified. The service contract contained five tasks. This report describes the results of task 1: the development of an integrated approach. In response, the model MITERRA-EUROPE has been developed on the basis of the models CAPRI and RAINS. It is a model that can be used to assess the effects of the implementation of ammonia and nitrate measures on the emissions of ammonia, nitrous oxide, nitrogen oxides, and methane to the atmosphere, and leaching of nitrogen to ground water and surface waters on both EU-27 level, country level, and regional level.

Keywords: agriculture, ammonia, European Union, measures, nitrate, nitrous oxide, policy, nitrogen

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P.O. Box 47; 6700 AA Wageningen; The Netherlands
Phone: + 31 317 474700; fax: +31 317 419000; e-mail: info.alterra@wur.nl

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Summary

The European Commission, Directorate-General Environment has contracted Alterra, Wageningen UR for the Service contract "Integrated measures in agriculture to reduce ammonia emissions". The general objective of the service contract is to define the most appropriate integrated and consistent actions to reduce various environmental impacts of N (N) from agriculture, notably the effects on quality of water and air and on greenhouse gas emissions. Specifically, the objective is to have developed and applied a methodology allowing to assess and quantify the effects and costs of various policies and measures aiming at reducing the impact of agriculture on water air pollution and climate change. Both ancillary benefits and trade offs of measures have to be identified. In this report, the integrated approach of task 1 is described: development of an integrated approach.

The model MITERRA-EUROPE is developed in this project. It is a model that can be used to assess the effects of the implementation of ammonia (NH_3) and nitrate (NO_3) measures and policies on the emissions of NH_3, (nitrous oxide) N_2O, N oxides (NOx), and methane (CH_4) to the atmosphere, leaching of N (including nitrate) to ground water and surface waters, and on the phosphorus (P) balance on both EU-27 level, country level, and regional (NUTS 2) level. It is a tool that can be helpful for tuning different N policies.

MITERRA-EUROPE consist of input module with activity data and emission factors, a set of (packages of) measures to mitigate NH_3 emission and N_3 leaching, a calculation module, and an output module. The starting point for MITERRA-EUROPE are the existing models CAPRI, RAINS, MITERRA-NL, and INITIATOR, supplemented with existing data bases (e.g FAO and Eurostat), soil data and expertise about emission processes. The data-base of MITERRA-EUROPE is on NUTS 2 level and includes data of N inputs, N outputs, N surplus, land use, crop types, soil type, topography, livestock numbers etc., and emission factors for NH_3, N_2O, NO_X and CH_4, and leaching factors for NO_3.

The results of the scenario analyses lead to the following conclusions:

- The NH_3 emission abatement measures of the UNECE Working Group on Ammonia Abatement Technologies are effective in decreasing NH_3 emission, but some of these measures increase the emissions of N_2O and the leaching of N. The measures 'low-protein animal feeding' and 'N management' have the potential of inducing synergistic effects, i.e., decreasing all N losses simultaneously. When the NH_3 emission abatement measures are implemented as integrated package and emphasis is given to 'overall N management', the possible antagonistic effects may disappear.
- The NO_3 leaching abatement measures of the Nitrates Directive are effective in decreasing N leaching, but some have the potential to increase the emissions of NH_3 according literature. Assessments made by MITERRA-EUROPE indicate indeed that the measures of the Nitrates Directive are effective in decreasing N

leaching and that the antagonistic effects are relatively small. Overall, the NO_3 leaching abatement measures of the Nitrates Directive (especially balanced fertilization) have the potential of creating synergistic effects.

- The RAINS A 2020 scenario leads to a ~10 % decrease in NH_3 emission in EU-27 by 2020 relative to the reference year 2000, mainly due to a lower N fertilizer use and a less N excretion (due to less domestic animals). The leaching of N to groundwater and surface waters decreases by 9 %. Differences between countries are large.
- The RAINS optimized 2020 scenario lead to a ~21 % decrease in NH_3 emission in EU-27 by 2020 relative to the reference year 2000, mainly due to the implementation of 'cost-effective' NH_3 emission abatement measures. The leaching of N to groundwater and surface waters decreases by 10%.
- The Nitrates Directive scenarios have a strong effect on the N input via fertilizer and animal manure, and hence on N losses. The ND full 2020 and the WFD 2020 scenarios lead to a ~29 and 31 % decrease in N leaching in EU-27 by 2020 relative to 2000, respectively. The NH_3 emission decrease by 14 and 17% in the ND full 2020 and the WFD 2020 scenarios, respectively.
- The ND full 2020 and the WFD 2020 scenarios have significant effects for agriculture. Strict implementation of the code of Good Agricultural Practice and balanced N fertilization according to the Nitrates Directive, and 'equilibrium P fertilization' (in the WFD scenario) will strongly decrease 'the room for N and P fertilizer use and application of animal manure N and P' in various regions in EU-27. Achieving a strong decrease in the application of animal manure N and P will require a combination of low-protein and low-P animal feeding, as well as manure treatment.
- The ND full 2020 and the WFD 2020 scenarios, as defined here, greatly contribute to achieving the targets of the Thematic Strategy on Air Pollution. As yet, the RAINS optimized 2020 scenario did not include the effects of the ND full 2020 and WFD 2020 scenarios. This suggests that new optimizations runs may be needed, taking the measures of the Nitrates Directive and the Water Framework Directive into account.
- Denitrification, with emission of N_2 is the largest N loss pathway in European agriculture, followed by NH_3 volatilization, and N leaching. Emissions of N_2O and NO_X contribute little to the total N loss (but have a significant environmental effect).

The focus in this service contract was on the development and application of the integrated N model MITERRA-EUROPE. The NH_3 results were compared with those of the RAINS model and the other emissions were roughly compared with results of literature. On basis of expert knowledge is was concluded that results were plausible, but it is recommended to carry out an in-depth analyses of the results on both national and NUTS 2 level. The strong effects of the measures taken for ND full 2020 and WFD 2020 on N use, N leaching, gaseous N emissions and on crop yield and N off take demand further study. Quantitative sensitivity analyses are needed to assess the effects of major uncertainties in the input and assumptions of MITERRA-EUROPE.

1 Introduction

The European Commission, Directorate-General Environment has contracted Alterra, Wageningen UR for the Service contract "Integrated measures in agriculture to reduce ammonia emissions". The general objective of the service contract is to define the most appropriate integrated and consistent actions to reduce various environmental impacts of N (N) from agriculture, notably the effects on quality of water and air and on greenhouse gas emissions. Specifically, the objective is to have developed and applied a methodology allowing to assess and quantify the effects and costs of various policies and measures aiming at reducing the impact of agriculture on water air pollution and climate change. Both ancillary benefits and trade offs of measures have to be identified. The impacts and feasibility of the most promising measures have to be analyzed in depth.

The service contract describes the following five tasks:
1. Development of an integrated approach.
2. Analysis of International and European instruments
3. In depth assessment of the most promising measures
4. Impact assessment of a possible modification of the IPCC Directive
5. Stakeholder consultation, presentations, workshops.

In this report, the integrated approach of task 1 is described. A model (MITERRA-EUROPE) is developed in order to:

i) assess the effects of the implementation of ammonia (NH_3) abatement techniques on the emissions of NH_3, nitrous oxide (N_2O), N oxides (NOx), and methane (CH_4) to the atmosphere, leaching of N (including NO_3) to ground and surface waters, and on the phosphorus (P) balance;

ii) assess the effects of the implementation of measures to decrease NO_3 leaching on emissions of NH_3, N_2O, NOx, and CH_4, NO_3 leaching and the P balance.

In chapter 2, the different N emissions and risk of N policies on pollution swapping are described. In chapter 3 a description of MITERRA-EUROPE is given. In chapter 4 the scenarios that were assessed are described, including RAINS scenarios (Amann et al., 2006) and scenarios of implementation of the Nitrates Directive and Water Frame Work Directive. The results of the calculation of the different scenarios are presented and discussed in chapter 5. In chapter 6 the uncertainties in MITERRA-EUROPE are discussed and some suggestions for improvements are presented. In chapter 7 the conclusions are given. In the Annexes of this report detailed results are presented. The work in this task of the Service contract was reviewed by a group of scientists and discussed in a meeting in Wageningen in January 2007 (Annex 5).

2 Nitrogen emissions from agriculture to the environment

N (N) is a key element in protein, and the growth of plants heavily depends on the availability of N. The productivity of many ecosystems and especially agro-ecosystems is limited by shortage of plant-available N. The availability of relatively cheap N fertilizers from the 1950s onwards has contributed to a boost in crop production. The availability of the N fertilizers has indirectly also contributed to the increase in the number of farm animals and the production of N in animal manure. Excessive use of N in amounts that exceed plant needs can lead to numerous problems directly related to human health, and ecosystem vulnerability. N appears in various species, with various oxidation states, mobility and reactivity.

Galloway (2003) and Galloway et al. (2002) made an integral analysis of the cause - effect relationship between the creation of N and a sequence of environmental effects. Observed environmental effects include

- decreased species diversity and acidification of non-agricultural soils because of deposition of NH_3;
- pollution of ground water and drinking water due to NO_3 leaching;
- eutrophication of surface waters, including excess algal growth and a decrease in natural diversity due to N leaching and run-off;
- global warming because of emission of the greenhouse gas N_2O, and
- impacts on human health and plants due to ozone for which NOx is a precursor.

Agriculture is the main user of N. The recovery of N in the harvested crop from animal manure is much less than 50% (Oenema and Tamminga 2005). The difference between N application and N withdrawal via harvested crop is the N surplus. The greater part of the N surplus is lost to the environment, either as NH_3, NOx, N_2O or N_2 into the atmosphere, or as NO_3 and other N compounds into groundwater and surface waters (Figure 2.1).

Apart from increasing N emissions, increased inputs of fertilizer and manure in agriculture may also contribute to changes in the emissions of the greenhouse gas methane (CH_4), and the accumulation and/or elevated leaching and runoff of various compounds, including P (figure 2.1). N and P are generally considered to be the key elements controlling the ecological quality of fresh waters.

In response to the environmental side effects of the increase availability of fertilizer N and animal manure, series of governmental environmental policies and measures have been implemented in practice. These policies and measures specifically aim at decreasing the emissions of NH_3 in the atmosphere (NEC Directive and IPPC Directive), the leaching of NO_3 to groundwater and surface waters (Nitrate Directive and Water Framework Directive), and the emissions of the greenhouse gases CO_2, N_2O and CH_4 to the atmosphere (Kyoto Protocol).

Ammonia emissions originate for a major part (>90%) from agriculture. Many EU countries appear to have reached the current National Emission Ceiling (NEC) value in 2010, but others not. This means that still major effort is still needed for various countries (Kuczybski et al., 2005). The objectives for the Thematic Strategy on Air Pollution for 2020 are more strict and challenging for many countries.

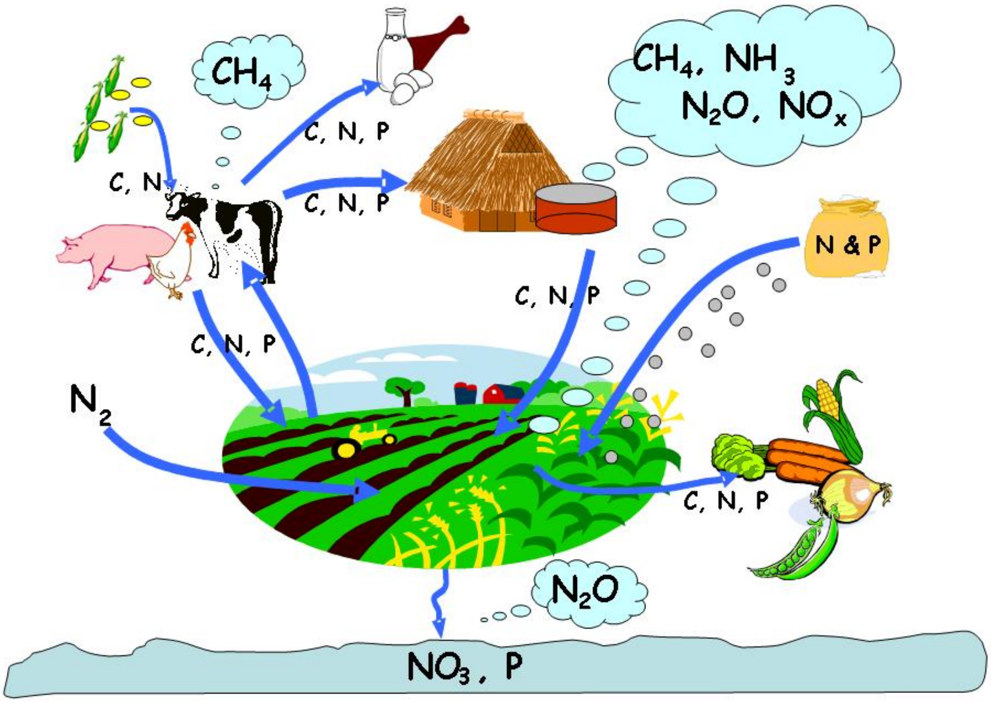

Figure 2.1. N (N), phosphorus (P), and carbon (C) flows in agricultural systems and emissions to the atmosphere, groundwater and surface water.

Depending on soil type and land use, a substantial portion of European groundwater bodies is affected by N from agricultural sources (Van Egmond et al., 2002; EEA, 2003). Nitrate is mobile and easily leaches to deeper soil layers. In various areas of Europe, the NO_3 concentration in shallow groundwater exceeds the standards of 50 mg per l of the Nitrate Directive. Ammonium is less mobile than nitrate in the soil, but can be transported to surface water via rapid water flows, such as surface runoff and subsurface flow. Also leaching of dissolved organic N to surface water occurs, especially in organic rich soils, such as peat soils and grassland soils. For the Rhine River, agriculture contributes 40 and 32% of the total loading of N and P, respectively (Van der Veeren, 2002).

Emission of N_2O from agricultural soils reflect the use of N fertilizer and manure intensity. Emission are highest from wet soils and soils with high organic matter contents. In terms of CO_2-equivalents, the European greenhouse gas emissions from agricultural soils are composed of 1% CH_4, 11% CO_2, and 89% N_2O (Freibauer et al., 2003).

Pollution swapping is generally seen as a response to governmental policies that focus on one N loss form. This pollution swapping is considered a common occurrence (Chambers and Oenema, 2004; Monteny et al., 2001).

The model MITERRA-EUROPE is a tool for integrated assessment of N emissions from agriculture on EU-27 level. The effects of N measures and policies can be quantitatively assessed and both ancillary benefits and trade offs of measures and policies can be identified.

3 Description of MITERRA-EUROPE

In this chapter, a description of MITERRA-EUROPE is presented. MITERRA-EUROPE is a model consisting of input module with activity data and emission factors, a set of (packages of) measures to mitigate NH_3 emission and N leaching, a calculation module, and an output module. The data-base of MITERRA-EUROPE is on regional (NUTS 2) level and includes data of N inputs, N outputs, N surplus, land use, crop types, soil type, topography, livestock numbers etc., and emission factors for NH_3, N_2O, NO_X and CH_4, and leaching factors for N.

The starting point for MITERRA-EUROPE are the existing models CAPRI (Common Agricultural Policy Regionalised Impact; http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm), RAINS (http://www.iiasa.ac.at/rains), MITERRA-NL (Velthof et al., 2002) and INITIATOR (De Vries et al., 2002), supplemented with existing data bases (FAO, Eurostat), soil data (CAPRI Dynaspat) and expertise about emission processes. MITERRA-Europe is programmed in the language GAMS. The advantage of using GAMS is that data bases and equations can be easily exchanged with CAPRI (which is also modelled in GAMS).

In paragraph 3.1 a brief explanation of the calculation method of MITERRA-EUROPE is presented. The sources of the used activity data are described in paragraph 3.2. The methods of calculating the emissions are presented in 3.3. In paragraph 3.4 an overview of the ammonia abatement techniques and measures to decrease N leaching that are implemented in MITERRA-EUROPE are given, including the methodology of calculation the effects of measures..

3.1 Method of calculation and input data

In figure 3.1, a schematic presentation of MITERRA-EUROPE is given. The following calculations are carried out:

- The total N excretion is calculated as the number of animal times the excretion per animal, for the different types of animals;
- Part of the N is excreted during grazing and part of the N is excreted in housing and stored in manure storage;
- Gaseous N losses (NH_3, N_2, N_2O, NO_X) from housing and storage are calculated using emission factors;
- Leaching from manure storage is calculated with leaching fractions;
- Some manure may be treated or exported (and not used in agriculture);
- Gaseous N losses (NH_3, N_2, N_2O, NO_X) from the different N sources of soils (manure, grazing, fertilizer, atmospheric deposition, biological N fixation) are calculated using emission factors;
- Surface runoff from the different N sources of soils is calculated with surface runoff fractions;
- The N removal via crop yield is calculated;

- The N surplus of the soil is calculated from the total N input, the N removal via crops, and gaseous N losses and surface runoff from the different N sources of soils (manure, grazing, fertilizer, atmospheric deposition, biological N fixation);
- The N surplus is divided in leaching below the rooting zone and denitrification using leaching fractions (leaching fraction = 1 – denitrification fraction).

The reference year of MITERRA-EUROPE is the year 2000. Measures that are implemented will start from the situation in 2000. MITERRA-EUROPE calculates emissions on NUTS-2 level, the level of nitrate vulnerable zones (NVZ; figure 3.3 and Annex 1), and country level. The 27 member countries of the EU are included. Croatia and Turkey are not included, because the required activity data and emission factors are not yet or only partly available.

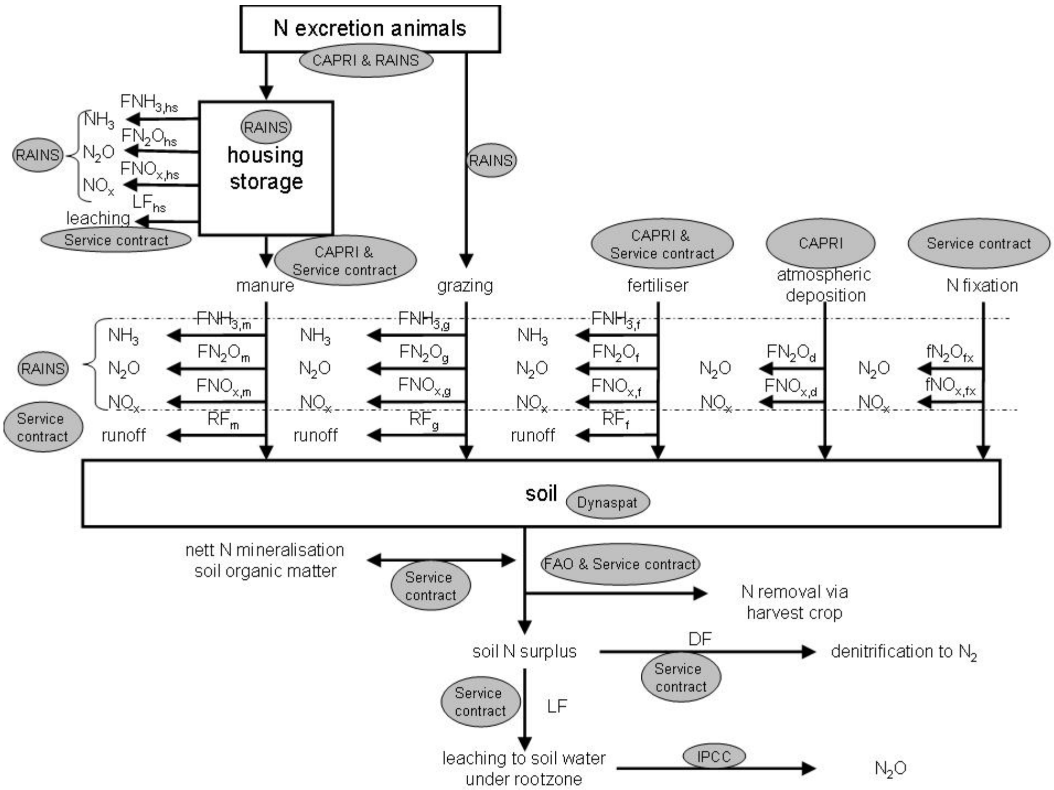

Figure 3.1. Schematic presentation of MITERRA-EUROPE. In grey the used sources of information are presented. The sources are RAINS, CAPRI, FAO, IPCC, and Dynaspat. Service contract means that the data/calculation is obtained in the current project. F indicates emission factor for gaseous emission, L leaching fraction, D denitrification fraction, and R runoff fraction.

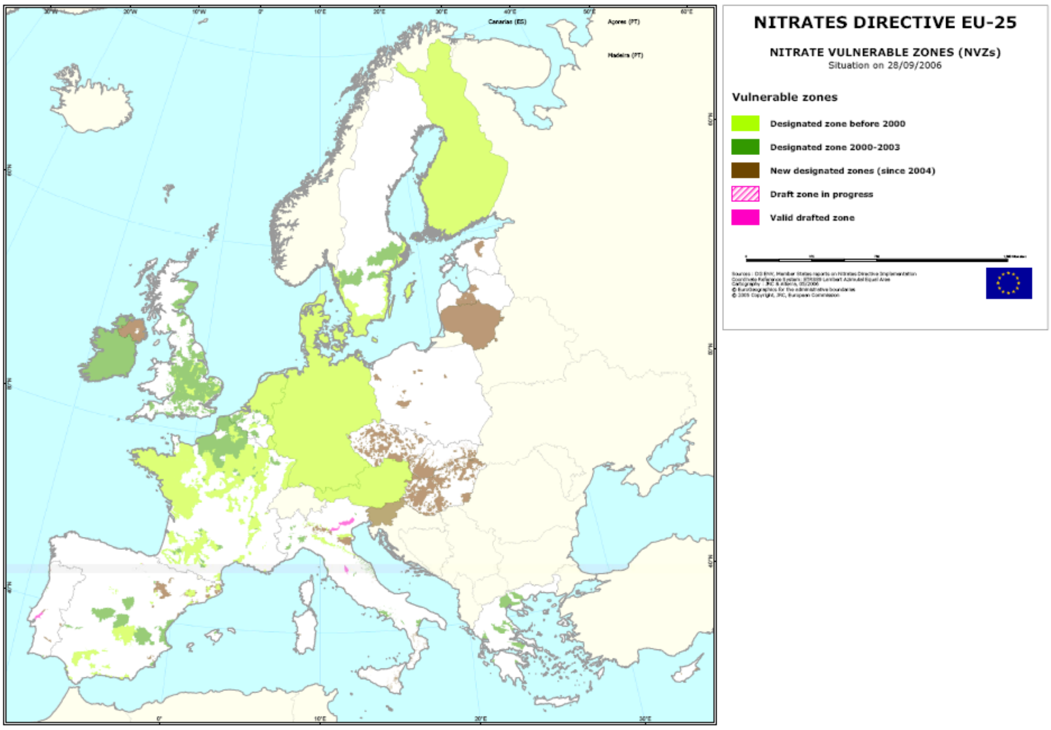

Figure 3.2. Nitrate Vulnerable Zones (NVZ) in EU-25 according to the Nitrate Directive. In Annex 1 the proportion of NVZ in the total area of the EU-27 are presented for the current situation and the predicted situation in 2020.

3.2 Activity data

3.2.1 Animals and housing systems

The animal categories and number of animals from RAINS scenarios are used in MITERRA-EUROPE. The RAINS data are available at the national (NUTS0) level. In CAPRI, number of animals are given on NUTS 2-level. For some animal categories, the total number per country differ between CAPRI and RAINS (because they are based on different statistical surveys). In MITERRA-EUROPE the number of animals of RAINS are used in order to be consistent with the ammonia emission calculations of RAINS. The distribution of the animals over NUTS 2 regions is calculated using the distribution of CAPRI. Data on housing systems and grazing period are derived from RAINS (on NUTS 0-level). The N excretion per animal head is also derived from RAINS.

3.2.2 Soil type and meteorological data

The leaching is calculated on the basis of crop, soil, and climatological data using the Homogenous Spatial Mapping Units (HSMUs) developed in the CAPRI-Dynaspat project. In this project, a statistical approach is developed to break down data of 30 crops in about 150 European administrative regions for EU15 (NUTS 2) to 100.000

HSMUs, using spatial information of the land cover/land use map (CORINE), Cover Area Frame Statistical Survey (LUCAS), soil map, digital elevation map, and climate map (see http://www.agp.uni-bonn.de/agpo/rsrch/dynaspat/pap04-05.pdf).

The NO_3 concentration in soil water is calculated from N leaching in kg N per ha and the water flux. It is assumed that all N that leaches from the rooting zone to deeper soil layer) is present as NO_3 (because transport of NH_4 in the soil is limited. The method to calculate the water flux is derived from Tiktak et al. (2006) and is based on data on precipitation and transpiration of cropped soils.

3.2.3 Crop area and yield

The area of crops in NUTS 2 regions are derived from CAPRI. However, in the present study three types of grasslands are distinguished: intensively managed grasslands, extensively managed grasslands, and rough grazing. The area of rough grazing are derived from Eurostat. Rough grazing includes grassland areas, moors (grassland areas mixed of bushes as heathers or gorses), mountain pastures (alpine or high altitude pastures used in summer), and all extensive pastures often located in fragile areas. These grasslands have low productivity, with yields below 1500 fodder units per hectare (1500 fodder units meet the needs of one ABU (adult bovine unit) during 6 months). The percentage of intensively managed and extensively managed grasslands are estimated in the current project. For Belgium, Denmark, and the Netherlands it is assumed that 75% of the managed grasslands is intensively managed, for Ireland this is 50%, and for the other countries 25%. These estimates are based on expert knowledge, the pastoral type map of the European pasture monograph and pasture knowledge base of the Pask study (http://agrifish.jrc.it/marsstat/Pasture%5Fmonitoring/PASK/INDEX.HTM), and the assumption that the proportion of intensively managed grasslands decrease with increasing size of the country.

In table 3.1 estimates of the proportion of intensively managed grassland, extensively managed grasslands, and rough grazing are presented. Also the assumed dry matter yields and N contents are given. Because the statistics do not presented grassland yields, grassland yields were estimated using literature (Peeters & Kopec, 1996) and expert knowledge. For each country, the yield of extensively managed grassland was arbitrarily set at 50% of the yield intensively managed grassland (table 3.1). Also the N contents differed between intensively and extensively managed grassland, which reflects the effect of N input (the higher N input, the higher N content of grassland). It is assumed that there is no N input via fertilizer and manure to rough grazing and that yields are negligible. The area of rough grazing are considered when calculating emissions and balances on basis of hectare agricultural land, but no N input to and output from rough grazing are calculated. This means that a large area of rough grazing in a country dilutes the emissions from managed agricultural land on a hectare basis. It is strongly recommend to start a study in which the area of grassland types and their yields and N contents is determined for all countries, because this area significantly affects the results on hectare-basis.

The yields of arable crops were derived from FAO statistics. The N contents of crop products and the amount of crop residues were based on a literature review of Velthof & Kuikman (2000) for the Netherlands in which results of a large number of crops are presented (table 3.2). However, the results were derived from Dutch studies of the nineties. It is well-known that the N content of crops and crop residues is related to the N input. For example, the study of Lord et al. (2002) showed lower N contents for the UK than for the Netherlands. Therefore the N contents of Velthof & Kuikman (2000) were adjusted using a factor which is dependent on the amount of plant-available N. This plant-availability factor derived as follows:

- The total average amount of plant-available in kg N per ha per country in 2000 was calculated (see paragraph 3.4.2).
- It is assumed that in the Netherlands the N content in 2000 is equal to those of Velthof & Kuikman (2000). The average plant-available N content in 2000 was 356 kg N per ha.
- It is assumed that the N content at the lowest plant-available N application rate in 2002 (i.e. 63 kg N per ha in Spain) is on average 35% lower than those of Velthof & Kuikman (2000).
- The correction factors for the other countries are calculated from the application rate of plant-available N, assuming a linear relation between plant-available N application rate and the correction factor:

  correction factor = 0.119*plant-available N (kg N per ha) + 57.53.

The calculated N yields of a selection of crops are presented in table 3.3. A simple approach to calculate N yields was chosen in this project, but there is clear scope to improve the estimates. It is recommended to start to study to obtain country and crop specific N contents and crop residues in order to improve the calculation of N surplus and N demand.

Measures can affect the amount of applied plant-available N (e.g. storage of manures leads to less NH_3 emission, and therefore more N in manure). This also may affect the yield of the crop. In MITERRA-EUROPE a simple general approach is chosen to correct yields on changes in applied plant-available N.

- the amount of applied plant-available N in 2000 and in the scenario are calculated (see paragraph 3.4.2).
- the N yield in the scenario is calculated as
-

$$\text{Total N content}_{scenario} = \text{Total N content}_{2000} * [1+ \text{factor}_{rain\ surplus} * ((\text{Pa. N}_{scenario} - \text{Pa. N}_{2000}) / \text{Pa. N}_{2000})]$$

$$\text{N residue}_{scenario} = \text{Total N content}_{scenario} / (\text{N-index} + 1)$$

$$\text{N yield}_{scenario} = \text{Total N content}_{scenario} - \text{N residue}_{scenario}$$

Where

- Total N content is the total N content of the crop (kg N per ha).
- Pa. N is the amount of applied plant-available N (kg N per ha).
- N residue is the total N content of the crop residue (kg N per ha).

- N yield is the total N yield in kg N per ha, i.e. the N removed via the harvested crop.
- N-index is the ratio between N yield and N in crop residue (kg N per ha)
- $factor_{rain\ surplus}$ is correction factor for the surplus in water via rain (i.e. rainfall – evapotranspiration). It is assumed that an increase in plant-available N only increase the N yield when there is a sufficient amount of water. It is assumed that this related to the rain surplus.

The maximum rain surplus on NUTS 2 level is 655 mm and the minimum is 35 mm. The factor $factor_{rain\ surplus}$ is arbitrarily set at 75% for 655 mm and 25% for 35 mm and assuming that there is a linear relation between this factor and the rain surplus:

$Factor_{rain\ surplus}$ (%) = 22.2 + 0.081*Rain surplus

For the new member states, it is assumed that crop yields increase with 15% from 2000 to 2020, because of intensification after joining the EU. For the old member states no increases is assumed, because there has been already a period of strong intensification or because the climatological conditions do not allow further yield increase (e.g. because of drought in South Europe and because of temperature and light in N Europe).

Table 3.1. Dry matter and N contents of grassland and proportion of grassland types.

Country	nett dry matter yield,		N content, % DM		proportion, % of total grassland area			average	average N	average N
	intensively managed	extensively managed	int	ext and rough grazings	intensive	extensive	rough grazing	dry matter yield	content, % DM	yield, kg N per ha
Austria	6000	3000	3	2	13	40	47	3750	2.25	84
Belgium	9000	4500	3	2	75	25	0	7875	2.75	217
Bulgaria	4000	3000	3	2	17	52	31	3250	2.25	73
Cyprus	4000	3000	3	2	17	51	32	3250	2.25	73
Czech rep.	5000	3500	3	2	25	74	1	3875	2.25	87
Denmark	9000	4500	3	2	73	24	2	7875	2.75	217
Espagne	5000	3000	3	2	12	35	53	3500	2.25	79
Estonia	5000	3000	3	2	25	75	0	3500	2.25	79
Finland	6000	3000	3	2	21	63	16	3750	2.25	84
France	7000	3500	3	2	8	24	68	4375	2.25	98
Germany	8000	4000	3	2	24	73	3	5000	2.25	113
Greece	4000	3000	3	2	8	24	68	3250	2.25	73
Hungary	5000	3500	3	2	14	42	44	3875	2.25	87
Ireland	8000	4500	3	2	43	43	15	6250	2.50	156
Italy	5000	3000	3	2	20	59	21	3500	2.25	79
Latvia	5000	2500	3	2	4	13	83	3125	2.25	70
Lithuania	5000	2500	3	2	25	75	0	3125	2.25	70
Luxembourg	9000	4000	3	2	25	75	0	5250	2.25	118
Malta	4000	3000	3	2	25	75	0	3250	2.25	73
Netherlands	10000	5000	3	2	72	24	4	8750	2.75	241
Poland	5000	3500	3	2	18	54	28	3875	2.25	87
Portugal	5000	3000	3	2	7	22	71	3500	2.25	79
Romania	5000	3000	3	2	23	70	7	3500	2.25	79
Slovakia	5000	3000	3	2	23	69	9	3500	2.25	79
Slovenia	5000	3500	3	2	21	63	16	3875	2.25	87
Sweden	7000	3500	3	2	23	68	9	4375	2.25	98
United Kingdom	8000	4500	3	2	14	43	43	5375	2.25	121

Table 3.2. N contents and N index (= N yield/N residue) of the crops (based on Velthof & Kuikman, 2000).

	kg N per ton harvested product	Nindex
Apples	0.5	2.1
Barley	17	2.4
Citrus Fruits	0.5	2.1
Durum wheat	20	3.0
Flowers	5	2.1
Gras	30	2.0
Fodder maize	15	4.9
Grain maize	13.9	1.5
Nurseries	5	2.1
Oats and summer cereal mixes without triticale	17	2.1
Other cereals	15	2.0
Other crops	5	2.1
Fodder other on areable land	5.8	2.4
Other fruit	0.5	3.0
Other industrial crops	4	1.1
Olives for oil	0.5	2.1
Other oils	34	1.3
Other vegetables	2.5	1.2
Other wine	0.5	2.1
Paddi rice	20	3.0
Potatoes	3.5	3.1
Pulses	42	5.0
Rape	35	1.8
Fodder roots	1.9	1.8
Ryem	14	1.8
Soya	58	2.1
Sugar beet	1.8	0.7
Sunflowes	32	1.8
Soft weat	20	3.0
Table olives	5	2.1
Table grapes	1.9	2.1
Flax and hennep	4	1.1
Tobacco	30	2.1
Tomatoes	1	3.0
Wine (table)	0.5	2.1

Table 3.3. N yields in kg N per ha in 2000 calculated with MITERRA-EUROPE. For some crops, there are no estimates of yields available. The yields of these crops are set arbitrarily at 50 kg N per ha.

	AT	BG	BL	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HU	IR	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Apples	14	5	21	4	13	5	13	1	6	5	2	9	6	8	10	1	19	1	3	17	2	4	3	5	26	15	5
Barley	47	30	106	11	44	75	81	24	30	37	44	80	33	101	46	27	96	21	60	104	31	19	24	49	27	39	75
Citrus Fruits	0	0	0	9	0	0	0	0	7	6	0	5	0	0	6	0	0	0	5	0	0	4	0	0	0	0	0
Durum wheat	65	38	0	25	0	123	0	0	39	40	0	105	51	0	48	0	0	0	0	0	0	21	31	0	0	60	123
Flowers	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0	50	50	50	50	50	50	50	50
Gras	84	73	217	73	87	113	217	79	73	79	84	98	87	156	79	70	118	70	0	241	87	79	79	98	87	79	121
Fodder maize	108	17	152	0	75	50	112	50	104	90	0	101	45	50	106	50	137	50	0	165	65	58	16	50	36	63	50
Grain maize	100	16	140	0	70	50	0	0	97	83	0	93	41	0	98	50	127	0	0	153	60	54	15	0	34	58	0
Nurseries	50	50	50	0	50	50	50	50	50	0	50	50	50	50	50	50	50	0	0	50	0	50	50	50	50	0	50
Oats	44	13	84	14	36	73	63	25	24	24	44	56	20	106	28	21	76	19	0	94	23	15	12	48	16	29	77
Other cereals	54	30	89	50	44	59	68	50	50	25	50	57	30	50	50	26	80	22	50	82	29	17	50	50	26	50	71
Other crops	138	31	162	123	57	104	156	38	108	101	91	69	59	149	101	50	146	35	52	250	83	91	37	72	46	90	81
Other fodder crops	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Other fruit	5	1	20	4	4	2	7	1	5	3	1	4	3	5	5	1	18	1	2	15	2	2	2	2	3	5	5
Other industrial crops	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0	50	50	50	50	50	50	50	50
Olives for oil	0	0	0	50	0	0	0	0	50	50	0	50	0	0	50	0	0	0	50	0	0	50	0	0	1	0	0
Other oils	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0	50	50	50	50	50	50	50	50
Other vegetables	69	15	81	62	29	52	78	19	54	51	45	35	29	75	50	25	73	18	26	125	42	46	19	36	23	45	41
Paddi rice	0	63	0	0	0	0	0	0	101	92	0	86	50	0	83	0	0	0	0	0	0	81	35	0	0	0	0
Potatoes	75	18	141	49	58	122	128	35	52	59	62	102	46	98	65	38	127	33	60	160	48	37	29	76	43	52	108
Pulses	72	13	151	36	69	132	101	47	50	23	69	137	49	179	48	51	136	53	96	184	56	17	26	73	58	57	124
Rape	62	31	94	0	71	85	94	31	0	36	35	76	38	93	29	34	85	33	0	127	55	0	26	64	41	50	78
Fodder roots	41	10	77	27	32	66	69	19	28	32	34	56	25	53	35	21	69	18	33	87	26	19	16	41	24	28	58
Ryem	36	10	56	0	37	60	56	19	20	18	25	48	20	0	31	22	50	18	0	68	19	10	15	55	23	26	66
Soya	90	26	0	0	56	0	0	0	84	82	0	111	57	0	153	0	0	50	0	0	50	0	23	0	38	101	50
Sugar beet	78	13	111	0	64	83	90	50	82	74	43	101	44	85	62	38	100	38	0	110	50	72	17	62	44	55	73
Sunflowes	57	18	0	0	53	50	0	0	31	23	50	60	37	0	50	0	0	0	0	0	50	12	18	50	44	25	50
Soft weat	50	38	144	25	66	123	118	28	39	40	53	105	51	157	48	44	130	50	71	167	46	21	31	86	50	60	123
Table olives	0	0	0	0	0	0	0	0	50	50	0	50	0	0	50	0	0	0	0	0	0	50	0	0	0	0	0
Table grapes	0	50	50	50	0	0	0	50	50	50	0	50	50	0	50	0	50	0	50	50	50	50	50	0	50	50	0
Flax and hennep	50	50	24	0	6	0	50	3	50	2	50	4	50	0	0	2	0	2	0	7	5	0	6	50	0	50	5
Tobacco	45	23	82	115	0	50	0	0	48	59	0	60	39	0	74	0	0	0	0	0	45	59	20	0	0	50	0
Tomatoes	112	10	219	62	12	174	124	32	34	39	203	86	24	65	41	4	197	7	36	433	11	38	9	258	16	15	290
Wine (table)	50	50	50	0	50	50	0	0	50	50	0	50	50	0	50	0	50	0	0	0	0	50	50	0	50	50	50

3.2.4 N input to soils

The total manure production is calculated on NUTS 2 level from the number of animals and the N excretion. After correction for losses (gaseous and leaching) in housings and storage, and after correction for grazing (based on RAINS) the manure is distributed over different crop groups, i.e. fodder crops (with high application of manure) and three arable crop groups (with different application rates of manure). The distribution of manure of crops is based on estimates from literature (Menzi, 2002) and expert knowledge.
The amount of manure applied to fodder crops (grown in livestock farming systems and having a high manure application rate) is calculated according table 3.4. It is assumed that similar amounts of manure are applied to grasslands and other fodder crops.

The remaining manure is applied to arable crops. Firstly, the average manure application rate (in kg N per ha) for the three arable crop groups is calculated:

- group I (high use of manure): potatoes, sugar beet, other crops, other vegetables, barley, rape, and soft wheat;
- group II (intermediate use of manure): durum wheat, rye and meslin, oats and summer cereal mixes without triticale, grain maize, other cereals including triticale, and sunflower;
- group III (low use of manure): fruits, trees, olives, oil crops, citrus, grapes and other crops.

The application rate (kg N/ha) of group III is set at 10% of the average of the three groups, the application rate (kg N/ha) of group II is at 75% of the average. The remaining part of the manure is added to group I, so that largest amount of manure are applied to crops of group I.

For calculations of the year 2000, it is assumed that there is no manure transport between NUTS 2 regions. However, in calculations of future scenarios, manure may be transported between NUTS 2 regions.

Table 3.4. Distribution of manure of different animal types on fodder crops (per NUTS 2 region), i.e. grassland, fodder maize, and other fodder crop.

	% of manure to fodder crops				
	dairy cattle	other cattle	pigs	poultry	other
Austria	100	100	25	0	100
Bulgaria	100	100	25	0	100
Belgium	100	100	75	0	100
Cyprus	100	100	25	0	100
Czech ep.	100	100	25	0	100
Germany	100	100	50	0	100
Denmark	100	100	50	0	100
Estonia	100	100	25	0	100
Greece	100	100	25	0	100
Espagne	100	100	50	0	100
Finland	100	100	25	0	100
France	100	100	50	0	100
Hungary	100	100	25	0	100
Ireland	100	100	50	0	100
Italy	100	100	50	0	100
Lithuania	100	100	25	0	100
Latvia	100	100	25	0	100
Malta	100	100	25	0	100
Netherlands	100	100	75	0	100
Poland	100	100	50	0	100
Portugal	100	100	50	0	100
Romania	100	100	25	0	100
Sweden	100	100	25	0	100
Slovenia	100	100	25	0	100
Slovakia	100	100	25	0	100
United Kingdom	100	100	50	0	100

The national fertilizer consumption rates are derived from FAO (which is similar to CAPRI). The mineral fertilizer is distributed over crops on country level using weighing factors. The weighing factors were calculated from the N demand of the crop (= N in harvested products + N in crop residues) and the total area of the crop. The N contents in harvested products and crop residues and the amount of crop residues are based on Velthof & Kuikman (2000), as indicated in the previous paragraph. Examples of mineral fertilizer application rates in 2000 are presented in table 3.4.

The biological N fixation for arable soils is set 2 kg N per ha (a standard value for free living soil bacteria that can fix N) and for grassland at 5 kg N per ha (free living bacteria and clover). The amount fixed N by pulses and soya is set to the N in the harvested products.

The atmospheric N deposition is derived from CAPRI. A simple approach to correct the N deposition for changes in NH_3 emission is included in the model. In scenarios the N deposition is proportionally adjusted to changes in NH_3 emission (thus when NH_3 emission changes with X% than N deposition also changes with X%).

RAINS calculates emissions of NH_3 and N_2O on a national level. The total N input via fertilizers and manure are the same for RAINS and MITERRA-EUROPE, because the number of animals, excretion per animal, and the amount of fertilizer used are the same. In order to calculate leaching, and to calculate effects of measure "balanced N fertilization" MITERRA-EUROPE distributes the manure and fertilizers over crops and NUTS 2 regions. This does not affect the results of the calculations on a national level of NH_3 and N_2O emissions.

3.3 Calculation of emissions and flows

3.3.1 Emissions of ammonia, nitrous oxide, NO_x, and methane

The emission factors for NH_3, N_2O, NO_x and CH_4 are derived from the RAINS/GAINS model (Klimont and Brink, 2004), so as to maintain consistency in the environmental assessments. For the N_2O and CH_4 emissions, the default IPCC method is used. These national emission factors of RAINS are used on NUTS-2 level. No specific NUTS-2 emission factors are derived for NH_3, N_2O, NO_x and CH_4.

3.3.2 Changes in soil organic N

For the other soils, it is assumed that the organic N contents in the soil is on average (on large time scale of year and a large space scale of NUTS 2 regions) is in equilibrium and that there is no net mineralization or immobilization of N. For most situations this is a reasonable assumption, except when there are clear changes in land use (e.g. conversion of arable land in grassland or the opposite) or in N input. On smaller time and spaces scales, there will be changes in organic N contents of the soil, which may affect crop yields and N-emissions. Peat soils contain large amounts of organic N. This organic N may be mineralized when peat soils are drained for agricultural use. The amount of N released from drained peat is dependent on the drainage and peat type (Heathwaite 1991; Schothorst, 1977). In the Netherlands, drained peat soils are used for agriculture. In these soils mineralization may amount to more than 100 kg N per ha per year. However, in other countries peat soils are often only used as very extensive grasslands or rough grazing. The peat in these soils probably also contain less nutrients. Because of these uncertainties, mineralization of peat soils is not included in the calculations. However, it is derived more information on the properties and use of peat soils in EU-27, so that mineralization of these soils can be estimated and included in MITERRA-EUROPE.

Table 3.5. Mineral fertilization application rates in kg N per ha in 2000 calculated with MITERRA-EUROPE.

	AT	BG	BL	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HU	IR	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Apples	9	4	15	5	14	7	12	1	6	1	3	9	6	5	9	1	19	0	2	15	3	2	1	5	39	10	4
Barley	28	21	65	13	44	90	68	12	25	4	65	67	32	62	36	19	86	7	39	78	37	11	9	43	35	24	46
Citrus Fruits				13					7	1		4			6				4			2					
Durum wheat	36	24		29		138			31	4		83	46		35							11	11			35	71
Flowers	59	68	62	121	101	121	84	52	85	11	149	85	96	61	80	71	91	34		76	120	56	37	88	131	62	62
Gras	58	57	153	102	101	156	210	47	72	10	144	96	96	110	72	57	123	27		210	120	51	34	99	131	56	86
Fodder maize	64	12	94		76	61	95	26	89	10		86	43	31	85	35	124	17		126	78	33	6	44	48	39	31
Grain maize	82	15	119		97	83			114	12		109	55		108	49	158			160	99	42	8		61	49	
Nurseries	59	68	62		101	121	84	52	85		149	85	96	61	80	71	91			76		56	37	88	131		62
Oats	27	9	54	18	38	91	55	13	21	3	68	49	20	68	24	15	71	7		74	28	9	5	44	22	18	49
Other cereals	33	21	57	63	46	75	60	27	45	3	78	51	30	32	42	19	76	8	34	65	37	10	19	46	35	32	46
Other crops	85	22	104	155	60	131	137	20	96	11	140	61	59	95	84	37	138	12	35	198	104	53	14	66	63	58	52
Other fodder crops	59	68	62	121	101	121	84	52	85	11	149	85	96	61	80	71	91	34	65	76	120	56	37	88	131	62	62
Other fruit	3	1	13	5	5	3	6	0	4	0	1	4	3	3	4	1	17	0	2	12	3	1	1	2	4	3	3
Other industrial crops	43	49	45	88	74	88	61	38	62	8	108	62	70	45	58	51	66	24		55	87	41	27	64	95	45	45
Olives for oil				69					49	6		48			45				37			32			1		
Other oils	59	68	62	121	101	121	84	52	85	11	149	85	96	61	80	71	91	34		76	120	56	37	88	131	62	62
Other vegetables	63	16	77	115	45	98	102	15	71	8	104	46	44	71	62	27	102	9	26	147	77	40	11	49	47	43	39
Paddi rice		40							80	9		68	44		61							42	12				
Potatoes	49	13	96	65	65	162	118	20	49	7	102	95	49	66	57	29	127	12	44	133	64	23	12	74	62	35	73
Pulses	39	8	86	40	64	146	78	22	39	2	95	107	44	101	35	33	113	16	58	129	62	9	9	59	71	32	70
Rape	44	25	69		86	123	95	19		5	61	77	44	68	28	29	92	13		115	78		12	68	64	37	57
Fodder roots	31	8	62	42	42	104	76	13	31	4	66	61	31	42	36	19	82	8	28	86	41	14	8	47	40	22	47
Ryem	23	7	37		41	79	51	11	19	2	40	44	21		27	17	50	7		56	24	6	6	53	33	17	44
Soya	61	20			65				81	10		107	62		140			19			68		10		56	71	35
Sugar beet	88	16	131		124	192	145	49	133	15	121	164	81	100	94	51	173	24		160	116	77	12	103	109	65	86
Sunflowes	41	14			65	72			31	3	89	60	42		48						72	8	8	53	68	18	37
Soft weat	28	24	83	29	62	138	93	13	31	4	73	83	46	90	35	29	110	16	43	118	51	11	11	71	60	35	71
Table olives									85	11		85			80							56					
Table grapes		68	62	121				52	85	11		85	96		80		91		65	76	120	56	37		131	62	
Flax and hennep	43	49	22		8		61	2	62	0	108	4	70		1	2		1		8	10		3	64		45	4
Tobacco	31	18	58	158		69			47	7		58	42		68						61	38	8			35	
Tomatoes	68	7	138	76	12	215	107	17	30	4	309	75	23	41	33	3	183	2	24	336	13	22	3	231	22	9	183
Wine (table)	59	68	62		101	121			85	11		85	96		80		91					56	37		131	62	62

3.3.3 N leaching

The Nitrates Directive aims at decreasing the NO_3 leaching from agricultural sources to groundwater and surface waters. This includes the leaching of nitrate from fertilizer and manure applied to land. Special attention in the Codes of Good Agricultural Practice of the Nitrates Directive is paid to prevent/decrease the N leaching from stored manure and manure and fertilizers applied to sloping soils. Therefore, a module is included in MITERRA-EUROPE to estimate leaching from stored manure and from sloping soils (via runoff).

The following N leaching pathways in soils are considered in MITERRA-EUROPE:
- Leaching from stored manure
- Runoff in agricultural soils
- Leaching below rooting depth in agricultural soils, dived into
- Leaching to larger surface water via subsurface flow
- Leaching to deep groundwater + small surface waters

In the following paragraphs a description of the three leaching pathways is given.

3.3.3.1 Leaching from stored manure

Manure stored in the open air on soil (without a floor) is susceptible for leaching and surface run-off.

In a study of Sommer and Dahl (1999) in Denmark N leaching losses were <0.4% of the initial N during composting (197 days) of deep litter from dairy cows housings in heaps. In a similar study, Sommer (2001) showed that most of the N loss during storage of solid deep litter from dairy cow houses was due to NH_3 volatilization. Leaching accounted for 2 to 3 percent of the initial N content. Only a little N was lost due to denitrification. A study of Dewes (1995) in Germany showed that 2.5 to 3.4 percent of initial amount of N in manure heaps leached to deeper soil layers during a period of 177 days. Ammonia losses were much higher (25-45 percent) in this study. Also a study of Eghball et al. (1997) in the USA pointed at low leaching losses during composting of cattle manure (i.e. total runoff of nitrate and ammonium < 0.5% of the initial N). These studies indicate that leaching during composting of manure in temporary manure heaps (storage time < 200 days) are low (i.e. < 4 percent of the initial N).

High concentrations of NO_3 (3000 mg N/litre), and NH_4 (5000 mg/litre) were found in the unsaturated zone beneath a 20 year old turkey litter storage on chalk in the UK (Gooddy, 2002). Below the top 5 meters of the profile, concentrations declined dramatically. Measurements of soil water under a long-term unlined cattle slurry lagoon in the UK showed that constituents of slurry moved in 20 years up to more than 30 meters depth (Gooddy et al., 2002; Wither et al., 1998). Just below the storage, high NH_4concentrations were found (up to more than 750 mg per litre), but no NO_3 could be detected. However, from about 8 m depth, nitrate concentration strongly increased (up to more than 750 mg per litre) and NH_4 decreased. This suggest that the soil beneath the slurry storage is anaerobic, whereas oxygen diffusion in deeper layers, creates aerobic conditions, stimulating nitrification. De Sutter et al. (2005) found high NH_4 concentrations in the upper 3 meter of the soil below cattle and pig manure lagoons in USA. Nitrate concentrations were low, but results of deeper layers were not available. It is often assumed that the soil surface is sealed by slurry, by which leaching losses are supposed to be small. However, the results indicate that in long-term cattle and pig slurry lagoons, NH_4 and NO_3 concentrations in the soil solution can be very high. Culley and Phillips (1989) showed significant N leaching from long-term unlined (earthen) dairy manure storages in the USA. They indicated that total N recovery of unlined dairy manure storages was 43 percent. This means that 57% of the stored manure N was lost, probably both by NH_3 volatilization, denitrification, and N leaching. Some rough estimates on bases of the paper of Ham and DeSutter (1999) suggest that about 5 percent of the stored NH_4 in swine-waste lagoons in USA (Kansas) was lost via seepage. The results indicate that N concentration in the groundwater below permanent manure storages can reach high concentrations.

Assumptions and calculation method.
For MITERRA-EUROPE, leaching fractions (i.e. percentage of stored N that is lost) for manure storage were estimated (table 3.6). These estimates were based on expert judgement, because there are only a few studies in literature in which leaching is expressed in percentage of the manure-N stored per year. Data on the distribution of the amounts of stored solid and liquid manures in countries are derived from RAINS. Also data on the percentage of covered manure storage in countries are derived from RAINS. Data for the presence of concrete floors in manure storages were estimated by Pietrzak (personal communication).

For the presence of concrete floors, the following assumptions are made:
- Central and South Europe: 75 percent of the liquid storages have a concrete floor
- North and West Europe: 90 percent of the liquid storages have a concrete floor
- Central and South Europe: 50% of solid manure storages have a concrete floor
- North and West Europe: 50% % of solid manure have a concrete floor

Table 3.6. Leaching fractions for stored manure.

Type of manure system	Concrete floor	Cover	Leaching fraction, % of stored N
Liquid/slurry	no	no	20
		yes	15
	yes	no	0
		yes	0
Solid	no	no	10
		yes	2
	yes	no	5
		yes	0

3.3.3.2 Surface runoff

Introduction
Schwaiger et al. (2006[1]) carried out a desk study as part of the current project to quantitatively assess the surface runoff of N from agricultural soils. The findings of this desk study are used to estimate leaching fractions for surface runoff in MITERRA-EUROPE.

Surface runoff occurs when rainfall exceeds a soil's maximum saturation level. When the soil is saturated and the depression storage filled and rain continues to fall, the rainfall will immediately produce surface runoff. If the amount of water falling on the ground is greater than the infiltration rate of the surface, runoff or overland flow will occur. The rate of runoff flow depends on the ratio of rain intensity to the infiltration rate. If the infiltration rate is relatively low, such as when a soil is crusted or compacted, and the intensity is high, then the runoff rate will also be high. Runoff specifically refers to the water leaving an area of drainage and flowing across the land surface to points of lower elevation. Runoff involves that rainfall intensity exceeds the soil's infiltration rate and a thin water layer forms that begins to move because of the influence of slope and gravity.

Important factors controlling surface-runoff are the type, period and amount of N application, the slope of the soil, soil type and properties, weather conditions (precipitation, frost), and hydrology. In MITERRA-EUROPE, the leaching fraction for surface-runoff is expressed in percent of the N applied as fertilizer and manure.

The major findings of Schwaiger et al. (2006) are:
- Parameters for a high risk of N surface runoff are:
- Weather conditions - heavy precipitation, snow melt, storm
- Soil conditions - soil with low infiltration rate
- N Fertilizer input - high amount of fertilizer
- Kind of vegetation (growing season). Korsaeth & Eltun (2000) experienced by comparing different land use methods that runoff can reach from 18 – 35 kg N ha^{-1} $year^{-1}$. Forage system had lower N runoff then arable systems.
- Traditional (conventional) tillage. Soil tillage is the key management to avoid or perpetuate the runoff fraction – not only the erosion particles. It is difficult to distinguish between N from leaching runoff and erosion. To separate the effects from different tillage methods data on tillage is needed. For Europe only estimations can be used to figure out the real situation.
- Steep slope

- Beside the weather conditions, the soil infiltration is of great importance preventing surface runoff. The soil infiltration depends on the soil texture (a sandy surface soil normally has a higher infiltration rate than a clayey surface soil), crust, compaction (an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface),

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[1] Elisabeth Schwaiger, Bettina Schwarzl & Gerhard Zethner (2006) Desk study of surface runoff from application of fertilisers and organic manure to soils. Umweltbundesamt, Austria

aggregation/structure, water content (the infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet), organic matter (organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops) and pores (top soil air capacity). The surface runoff is also influence by the kind of field fruits and the soil management.

- There is no literature about N surface runoff from different kind of fertilizer application.

- The estimation of the N surface runoff from different fertilizers depends on several parameters. In general the assumption is that 10-20 % of total N load in surface water is caused by surface runoff, the rest by leaching.

- If we assume that an adequate amount of fertilizer/manure is applied, the most important factors causing surface runoff are i) the amount of precipitation, ii) the slope and iii) the vegetation.

Assumptions and calculation method
Surface runoff fractions were estimated on basis of expert judgement. The surface-runoff fractions are expressed in percentage of the N applied via fertilizer and manure per year.
The following factors were included in the estimate:
- The slope
- Precipitation
- Soil type
- Crop

The surface runoff is calculated from the applied amounts of fertilizer and manure, a maximal surface runoff, and a set of leaching factors.

$$LF_{surface\ runoff} = LF_{surface\ runoff,\ max} * f_{lu} * MIN\ (f_p, f_{rc}, f_s)$$

In which
- $LF_{surface\ runoff}$ = leaching fraction for runoff in % of the N applied via fertilizer and manure (including grazing)
- $LF_{surface\ runoff,\ max}$ the maximum leaching fraction for different slope classes
- f_{lu} = reduction factor for land use or crop
- f_p = reduction factor for precipitation
- $f_{s\ =}$ reduction factor for soil type
- $f_{rc\ =}$ reduction factor for depth to rock

The slope is an important factor controlling surface runoff. Moreover, in the Nitrates Directive measures are mentioned that specifically aim at reducing surface runoff from sloping soil. Therefore, in MITERRA-EUROPE slope is included as a factor affecting surface runoff. For four slope classes, a maximum surface runoff factors are set. Also in flat areas, surface runoff can occur during wet periods, and especially on heavy textured soils.

The following slope classes and surface runoff factors are distinguished:
- Level (dominant slope ranging from 0 to 8 %): $LF_{surface\ runoff,\ max} = 10$
- Sloping (dominant slope ranging from 8 to 15 %): $LF_{surface\ runoff,\ max} = 20$
- Moderately steep (dominant slope ranging from 15 to 25 %): $LF_{surface\ runoff,\ max} = 35$
- Steep (dominant slope over 25 %): $LF_{surface\ runoff,\ max} = 50$

It assumed that smallest surface runoff occurs in grasslands, because the grassland soil is covered the whole year by a crop. Moreover, soil tillage is an important factor that may enhance surface runoff. Permanent grassland soils are not tilled. It is assumed that surface runoff is four times lower in grassland than for other agricultural land use types:
- For other land use: $f_{lu} = 1.00$
- For grassland: $f_{lu} = 0.25$

Surface runoff is dependent on rainfall. Largest runoff occur in periods with heavy rainfall in which soil are already wet. Thus, surface runoff occurs during events and this it is not possible to model such events in MITERRA-EUROPE which calculates losses on an annual basis. The precipitation surplus is chosen as an indicator of rainfall effect on surface runoff (table 3.7). It is assumed that surface runoff may also occur during wet conditions in dry regions (i.e. in regions with a low precipitation surplus).

Table 3.7. Reduction factors precipitation surplus: fp

Precipitation surplus, mm	fp
> 300	1
100 - 300	0.75
50 - 100	0.50
< 50	0.25

Soil type affects surface runoff, i.e. risk on surface runoff increases when clay content of the soil increases. The following reduction factors f_s are included:
- Very fine (clay > 60 %): $f_s = 1$
- Fine (35% < clay < 60%): $f_s = 0.90$
- Medium (18-35% clay): $f_s = 0.75$
- Coarse (18% < clay): 0.25
- Peat: 0.25

The last factor that is included is the depth to rock, because surface runoff is highest in shallow soil. The surface runoff factors for depth to rock are:
For a depth of less than 25 cm: $f_{rc} = 1$
For a depth of more than > 25 cm: $f_{rc} = 0.8$

3.3.3.3 Leaching below rooting zone

Introduction

The N surplus is the difference between the N input to soil via manures, fertilizer, atmospheric deposition, and biological fixation and the output via harvested crops. In MITERRA-EUROPE, the surplus is corrected for NH_3 emission from manure and fertilizer, and surface runoff. The corrected N surplus is divided in denitrification and leaching using leaching or denitrification fraction: denitrification fraction (DF) + leaching fraction (LF) = 1. This is the leaching below the rooting zone or top soil (about the upper 1 meter of the soil profile).

Denitrification is the microbial process in which NO_3 is reduced to gaseous N compounds. The most important factors controlling denitrification are i) the presence of an energy source for the denitrifying bacteria, mostly available organic carbon, ii) anoxic conditions, and iii) the nitrate content in the soil. If any of these conditions is not fulfilled, denitrification is unlikely. Denitrification is a microbial process, and therefore trivial factors affecting biological processes, such as the temperature and pH, may also affect denitrification.

Calculation method

The following approach is chosen to calculate leaching:

Step 1. The maximum leaching fraction ($LF_{soil\ type,\ max,}$ in % of N surplus that leaches below rooting depth) is set per soil type, assuming that soil type is the major factor controlling the ratio between leaching and denitrification. Soil type (or texture) strongly affects oxygen concentration. Moreover, in peat soils high organic C contents and generally high groundwater tables created conditions favourable for denitrification. In general, denitrification losses will increase in the order: sandy soil < loamy soils < clay soils <peat soil (Barton et al., 1999; Koops et al., 1996; Van Beek et al., 2003).

Step 2. The maximum leaching fraction is corrected for effects of land use (grassland versus arable land) using a reduction factor ($f_{lu:}$). Land use has a strong effect on available organic C contents in the soil and thereby on the ratio between leaching and denitrification.

Step 3. The leaching fraction per combination of soil type and land use is corrected for different factors that affect denitrification and leaching in soil, i.e.

- Reduction factor for soil organic content (fc), because denitrification potential increases with increasing organic C content. Part of this effect is already allowed for in land use, but differences in organic C content within arable soils and within grassland soils may also cause differences in denitrification.
- Reduction factor for precipitation surplus (fp). The precipitation surplus is in combination with soil texture an indicator for the wetness of the soil.
- Reduction factor for temperature (ft). At the same conditions, denitrification will be lower and NO_3 leaching higher in regions with low temperature than in regions with high temperature.

- Reduction factor for rooting depth (fr). The risk on N leaching below rooting zone increases when the rooting depth decreases. Studies clearly indicate that deeply rooting crops, can remove nitrate from the soil profile up to more than 1 meter (Kristensen & Thorup-Kristensen, 2004).

In the model we only account for the factor that has the largest (estimated) effect on leaching, i.e. the minimum of the four reduction factors fp, fr, ft, and fc.

Thus, the leaching faction (LF, in % of the corrected N surplus) is calculated as:

$LF = LF_{soil\ type,\ max} * flu * MIN\ (fp, fr, ft, fc)$.

The corrected N surplus is defined as
Total N input - total N output – NH_3 emission$_{soil}$ – N_2O emission$_{soil}$ - surface runoff

where
- total N input = N input via fertilizer, manure, grazing, atmospheric deposition, and biological N fixation
- total N output = N removed via harvested crop
- NH_3 emission$_{soil}$ = NH_3 emission from soil applied fertilizer, manure, and grazing
- N_2O emission$_{soil}$ = N_2O emission from soil applied fertilizer, manure, grazing, atmospheric deposition and biological N fixation
- surface runoff = surface runoff of fertilizer and manure

Step 1
The maximal leaching fractions are derived from results of a national monitoring network in the Netherlands, in which both the N surplus and the NO_3 concentration in the upper ground water for sandy soils and drainage and ditch water for clay and peat soils were determined. According to the measurements collected in the Monitoring Program 39% of the N surplus of grassland on sandy soils leaches to the groundwater (Schröder et al., 2005 & 2006; table 3.8). This is in agreement with results of Wachendorf *et al.* (2004) in Germany who found a leaching fraction of 30-40% on a similar soil type. Much higher leaching fractions are indicated by the Monitoring Program for arable land, up to 100 percent for dry sandy soils. These results suggest that in arable land on dry sandy soils, denitrification losses are negligible and that the total N surplus leaches below the rooting depth. The observed NO_3 concentrations are lower at the higher groundwater levelsl. This reduction of concentration ranges from 0% on sandy soils with 'deep' groundwater (mean highest groundwater table during winter (MHG) > 0.80 meter deep) to 57% on sandy soils with shallow groundwater (MHG < 0.40 meter deep). These figures are based on research carried out in the years 1982-1991 on field level (Van der Meer, 1991) on farm level (Boumans *et al.*, 1989; Breeuwsma *et al.*, 1991), as well as on experiments with lysimeters (Steenvoorden, 1988).

Table 3.8. Net leaching fractions (kg N leached per kg soil N surplus; s.d.'s based on yearly variation in brackets), as affected by land use and mean highest groundwater level (MHG) (Schröder et al., 2005& 2006 using data of the Dutch National monitoring programme).

Soil type	Net leaching fraction, kg/kg				Ratio leaching fraction arable land/grassland
	Arable land		Grassland		
Sand, MHG < 0.40 meter	0.50	(0.08)	0.18	(0.04)	0.36
Sand, 0.80 < MHG < 0.40 meter	0.75	(0.09)	0.28	(0.05)	0.37
Sand, MHG > 0.80 meter	1.06	(0.08)	0.39	(0.06)	0.37
Clay	0.31	(0.06)	0.11	(0.05)	0.35
Peat			0.04	(0.01)	
Average					0.36

The following maximum leaching fractions are used in MITERRA-EUROPE:
- Maximum leaching fraction on sandy soil (LFsand, max) = 1
- Maximum leaching fraction on loamy soil (LFloam, max) = 0.75
- Maximum leaching fraction on clay soil (LFclay, max) = 0.50
- Maximum leaching fraction on peat soil (LFpeat, max) = 0.20

Step 2
As indicated in table 3.8 the leaching fraction for grassland is on average 0.36 times the leaching fraction of arable land, for all soil types.

Thus, the reduction factor for land use (f_{lu}) is:
- For other land use: f_{lu} = 1.00
- For grassland: f_{lu} = 0.36

Step 3
The reduction factor for the precipitation surplus (fp) is dependent on soil type (table 3.9). It is assumed that leaching on sandy and loamy soils is highest when precipitation surplus is highest. However, a high precipitation surplus creates anaerobic soil conditions in peat and clay soils and therefore higher denitrification losses and lower leaching losses. Therefore, a smaller leaching fraction is assumed for peat and clay at a high rain surplus. For all soils, a small leaching fraction is assumed at low (or negative) precipitation surplus, because in dry regions with low precipitation surplus leaching may occur during heavy rainfall events. In table the reduction factors for precipitation used in MITERRA-EUROPE are presented .

Table 3.9. Reduction factor for precipitation surplus: fp

Precipitation surplus, mm	fp sand en loam	fp peat en clay
> 300	1	0.50
100 – 300	0.75	1
50 – 100	0.50	0.75
< 50	0.25	0.25

Soils with a very shallow rooting depth are more susceptible for leaching than soil with a deep rooting depth. The maximum leaching fraction is based on results from the Netherlands. In the Netherlands the average rooting depth is about 90 cm depth.

The reduction factors for rooting depth are:
Rooting depth < 40 cm: $f_r = 1$
Rooting depth > 60 cm: $f_r = 0.75$

Denitrification increases with increasing temperature. In MITERRA-EUROPE, the following leaching fractions are used, assuming the denitrification at 15 °C is twice of that at 5 °C (a general effect of temperature on microbial activity):
< 5 °C: $f_t = 1$
5-15 °C: $f_t = 0.75$
> 15 °C: $f_t = 0.50$

It is assumed that the denitrification decreases (and leaching fraction increases) when total C content of the soil decreases. The reduction factors for total C (f_{tc}) are:
< 1% $f_{tc} = 1$
1-2% $f_{tc} = 0.90$
2-5% $f_{tc} = 0.75$
> 5% $f_{tc} = 0.50$

The leaching fractions are calculated on HSMU-level. In the figure 3.3, a map of the leaching fractions is presented. The average leaching fraction in the NUTS 2 regions is calculated as the mean of the leaching fractions of the HSMU's within these regions. In MITERRA-EUROPE N leaching is calculated on the scale of NUTS 2 regions.

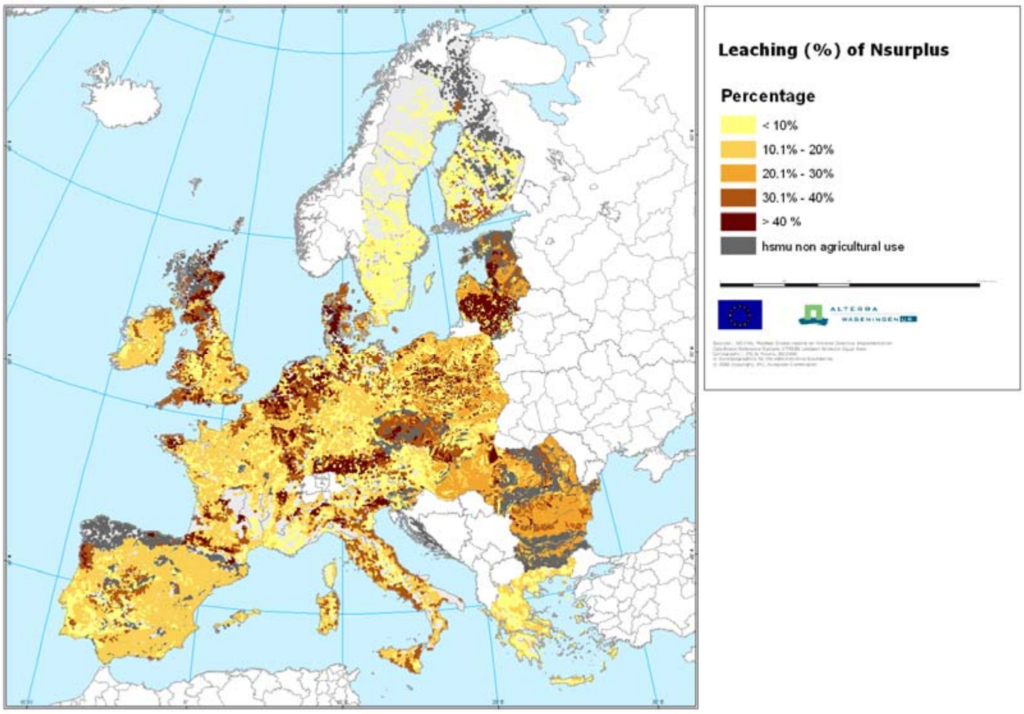


Figure 3.3. Leaching fractions in % of the N surplus.

Part of the N that has leached from the rooting zone will leach to deeper groundwater, part to surface water, and part is denitrified during transport to deeper soil layers. The leaching below rooting depth is divided in leaching to larger surface waters and leaching to groundwater + small surface waters. Large surface water is here defined as the surface water which is present on the CCM River and Catchment Database, version 1.0 (Vogt et al., 2003). This data base has a resolution of 250x250 meter. Small surface water such as ditches and creeks are not accounted for in the CCM Database.

The total leaching to the large surface waters via surface flow is arbitrarily set to the leaching below rooting zone of an area of 500 meter width near the large surface waters in agricultural regions. Firstly, the length of borders of large surface waters in agricultural regions on NUTS 2 level is calculated from the CCM River and Catchment Database and secondly, the total length of the border is multiplied with 500 m to obtain the area of leaching to larger surface waters (table 3.10). The area near surface from which leaching to the surface water occurs is strongly dependent on hydrological conditions of the soil, weather conditions, soil properties, (micro)-topography and crop type. Therefore, considerable differences between regions can occur. In this project, it was not possible to give a site-specific estimates of the area from which surface flows occurs in all NUTS 2 regions in EU-27 and therefore of simple approach was chosen.

Table 3.10. Total area of large surface waters and area of surface waters in agricultural regions and the length of the banks in EU countries.

	Area of surface water, ha		Length of banks of surface water, km	
	total	agricultural	total	in agricultural region
Austria	134262	32194	4210	1268
Belgium	72581	43056	3208	2318
Bulgaria	166912	75962	5886	3750
Cyprus	*	*	*	*
Czech Republic	133413	55713	5311	3024
Germany	932062	469381	31748	23942
Denmark	125656	70750	3889	3310
Estonia	447781	107381	8871	6014
Spain	830544	321656	31574	16487
France	1124913	625688	43736	31838
Greece	211006	50412	5976	2758
Croatia	87712	43306	2148	1346
Hungary	362856	249088	11073	10534
Ireland	1605475	380550	31172	18094
Italy	490125	137256	11714	7268
Lithuania	330950	151694	12404	9117
Luxembourg	2050	794	113	64
Latvia	444775	167288	13780	10132
Malta	*	*	*	*
Netherlands	435019	164319	6689	7356
Poland	1089275	527550	41415	30889
Portugal	180381	32694	5993	1858
Rumania	817112	349669	19288	16115
Sweden	7707150	229550	128587	11946
Slovenia	31562	10506	1520	609
Slovakia	52969	30188	2144	1546
UK	1202381	276550	42694	16939

3.3.4 Phosphorus balance

The phosphorus (P) surplus is calculated as follows:

P surplus = P input manure + P input grazing + P input fertilizer – P removal via crop, all in kg P_2O_5 per ha per year.

Data of P fertilizer input on NUTS 2 level are derived from CAPRI. The input of P via manure and grazing and the output via harvested products are calculated using the N results and N/P ratios of crops and manure. For crops, the N/P ratios from CAPRI are used.

The N excretion per animal head is derived from RAINS. The P excretion is calculated from the N excretion and fixed N/P ratios for animal categories (Table 3.11). These ratios are based on OECD, Dutch statistics, and Sheldrick et al. (2003).

Table 3.11. N/P_2O_5 ratios in crop products (Source: CAPRI)

	N/P_2O_5 ratio
Soft wheat	2.5
Durum wheat	2.9
Rye and meslin	1.9
Barley	1.9
Oats and summer cereal mixes without triticale	1.9
Grain maize	1.8
Other cereals including triticale	2.3
Paddy rice	3.1
Potatoes	2.5
Sugar beet	1.8
Fodder root crops	16.7
Pulses	3.4
Rape	1.8
Sunflower	1.8
Soya	3.6
Other oils	1.9
Flax and hemp	0.4
Grass	2.7
Fodder maize	1.6
Other fodder crops from arable land	3.1
Tomatoes	2.9
Other vegetables	2.9
Apples pears and peaches	3.7
Citrus fruits	5.0
Other fruits	5.0
Other crops	3.0
Nurseries	3.0
Flowers	3.0
Olives for oil	4.5
Table olives	4.5
Table grapes	1.9
Wine	1.9
Tobacco	7.5

Table 3.12. N/P_2O_5 ratios in animal excreta (Source: OECD, Dutch statistics, and Sheldrick et al., 2003).

	N/P_2O_5 ratio
Dairy cows	3.2
Other cows	2.5
Pigs	2.3
Laying hens	1.8
Other poultry	1.8
Horses	2.1
Sheep and goats	2.2
Fur animals	1.5

3.4 Measures

3.4.1 Ammonia emission

For each of the major sources of ammonia emissions (livestock farming, fertilizer use, and chemical industry), the model RAINS considers a number of emission control options. Ammonia emissions from livestock manures occur at four stages, i.e.,
(i) in the stable,
(ii) during storage of manure,
(iii) following its application and
(iv) during the grazing period.

At each stage, emissions can be controlled by applying various techniques. The major abatement categories for agriculture considered in RAINS are

- Low N Fodder (dietary changes), e.g., multi-phase feeding for pigs and poultry, use of synthetic amino acids (pigs and poultry), and the replacement of grass and grass silage by maize for dairy cattle;
- Stable Adaptation by improved design and construction of the floor (applicable for cattle, pigs and poultry), flushing the floor, climate control (for pigs and poultry), or wet and dry manure systems for poultry;
- Covered Manure Storage (low efficiency options with floating foils or polystyrene, and high efficiency options using tension caps, concrete, corrugated iron or polyester);
- Biofiltration (air purification), i.e., by treatment of ventilated air, applicable mostly for pigs and poultry, using biological scrubbers to convert the ammonia into nitrate or biological beds where ammonia is absorbed by organic matter;
- Low Ammonia Application of Manure, distinguishing high efficiency (immediate incorporation, deep and shallow injection of manure) and medium to low efficiency techniques, including slit injection, trailing shoe, slurry dilution, band spreading, sprinkling (spray boom system).
- urea substitution, substitution of urea with ammonium nitrate
- incineration of poultry manure

In MITERRA-EUROPE, the ammonia measures (and parameters) of RAINS (as listed above) are included. The removal efficiencies for NH_3, N_2O, and CH_4 on a country level (table 3.13) are used on NUTS 2 level. No refinement of the removal efficiencies on NUTS 2 level made. This means that it is assumed that the effect of measures, expressed as removal efficiency, is the same in all NUTS 2 regions within a country.

Table 3.13. The removal efficiencies for ammonia from RAINS on a country level (table 5.1 in Klimont & Brink, 2004).

Table 5.1: Emission control options for NH_3 considered in the RAINS model and their assumed removal efficiencies (based on the UNECE, 1999b: EB.AIR/WG.5/1999/8 Rev.1)[a].

		Removal efficiency [%]			
Abatement option	**Application areas**	*Animal house*	*Storage*	*Application*	*Grazing*
Low nitrogen feed (LNF)	Dairy cows	15	15	15	20
	Pigs	20	20	20	n.a.
	Laying hens	20	20	20	n.a.
	Other poultry	10	10	10	n.a.
Biofiltration (BF)[b]	Pigs, poultry	80	n.a.	n.a.	n.a.
Animal house adaptation (SA)	Dairy cows	25	80	n.a.	n.a.
	Other cattle	25	80	n.a.	n.a.
	Pigs	40	80	n.a.	n.a.
	Laying hens	65	80	n.a.	n.a.
	Other poultry	85	80	n.a.	n.a.
Covered storage (CS_low/high)	Dairy cows, other cattle, pigs, poultry *[liquid manure]*	n.a.	40/80	n.a.	n.a.
Low NH_3 application (LNA_low/high)	Dairy cows, other cattle, pigs, poultry, sheep *[solid waste]*	n.a.	n.a.	20/80	n.a.
	Dairy cows, other cattle, pigs *[liquid manure]*	n.a.	n.a.	40/80	n.a.
Urea substitution (SUB)	Fertilizer use	80 – 93			
Stripping/adsorption	Industry	95			
Manure incineration	Other poultry	~60 [c]			

[a] For some countries changes to these numbers where made as RAINS allows for country-specific reduction efficiencies, these was based on consultations with national experts during the work on the scenarios for Gothenburg Protocol. [b] Although some countries indicated that this option is also available for cattle (because some animal houses are equipped with mechanical ventilation), it has not been implemented in RAINS, yet. [c] Based on the example for UK, the values might vary from country to country.

n.a.: not applicable

Table 3.14. The removal efficiencies for nitrous oxide and methane RAINS on a country level (table 5.3 in Klimont & Brink, 2004).

Table 5.3: Impacts of NH_3 control options on emissions of N_2O and CH_4 (percentage changes in emissions).

		Sources of CH_4[b]	Sources of N_2O			
					Indirect emissions	
Control options	Livestock category	Manure management	Animal production	Direct soil emissions	*N deposition*	*N leaching*
Low nitrogen feed	dairy cows, pigs, poultry	0	–[a]	–[a]	–[a]	–[a]
Air purification		0	+[a]	0	–[a]	0
Animal housing adaptations	pigs	–10	900	+[a]	–[a]	+[a]
	poultry	–90	900	+[a]	–[a]	+[a]
Covered storage of manure	cattle, pigs, poultry	10	–10	+[a]	–[a]	+[a]
Low NH_3 application (low/high)	cattle, pigs, poultry, sheep	0	0	60/100	–[a]	+[a]
Urea substitution	fertilizer use	0	0	0	–[a]	0
Stripping/absorption	industry	0	0	0	–[a]	0

[a] The effect is calculated on the basis of changes in the N flow due to changes in excretion rates and N-volatilisation rates; [b] There are no effects of NH_3 abatement on CH_4 emissions from enteric fermentation.

3.4.2 N leaching

Within the Nitrates Directive two types of strategies to decrease N pollution can be distinguished:

i) code or codes of good agricultural practice for the whole country with the aim of providing for all waters a general level of protection against pollution. These codes of good agricultural practice have to be implemented by farmers on a voluntary basis (including provision of training and information for farmers).

ii) action programmes in respect of designated nitrate vulnerable zones (NVZ), including the measures of Annex III of the Directive and the measures for the Codes of Good Agricultural Practice. For most measures only outlines are given and the countries can fulfill these measures in different ways.

In MITERRA-EUROPE a list of measures to decrease N leaching is set up. It is assumed that packages of measures are implemented to decrease N leaching and to fulfill to the constraints of the Nitrates Directive. The degree of implementation of the different measures will vary between countries. The following measures to decrease N leaching in NVZ are included in MITERRA-EUROPE;

- balanced N fertilizer application;
- maximum manure N application standard of 170 kg N per ha (except where a derogation applies).
- no fertilizer and manure application in winter and wet periods
- limitation to fertilizer application on steeply sloping grounds
- manure storage with minimum risk on runoff and seepage

- appropriate fertilizer and manure application techniques, including split application of N
- prevention of leaching to water courses riparian zones buffer zones
- growing winter crops

For implementation of the Water Framework Directive (WFD) it is assumed that the following measures are taken:
- Full implementation of measures of the Nitrate Directive in Nitrate Vulnerable Zone;
- Decrease in input of P fertilizer and manure to decrease the risk on phosphorus leaching to surface water are included. The P input is decreased to a level that equilibrium fertilization of P is achieved ((P input via fertilizer and manure (excluding grazing) = P output via harvested crop).

For balanced N fertilization, the amount of N fertilizer applied and manure applied is tuned to the crop N demand, accounting for atmospheric deposition, mineralization, and biological N fixation.

The following approach is used in MITERRA-EUROPE:

I. The N demand of the crop is calculated:
IA. It is assumed that the crop yield (and N removed via harvested product) in 2000 is optimal for the region. Thus, with balanced N fertilizer application, the yield of 2000 must be achieved. The data of yields in 2000 are derived from FAO. For the new member states, it is assumed that crop yields increase with 15% from 2000 to 2020, because of intensification after joining EU. For the old member states no increases is assumed, because there has been already been a period of strong intensification or because the climatological conditions likely do not allow further yield increase (e.g. because of drought in South Europe and because of temperature and light in N Europe).

IB. The N uptake in the non-harvested crop parts (roots and crop residues) is estimated for each crop (using crop types of CAPRI). Data on the ratio between N in harvested products and N in crop residues are derived from Velthof & Kuikman (2000) and estimated in this project, as indicated in paragraph 3.2.3.

IC. From IA and IB the total N uptake by crops in each NUTS 2 region and NVZ is calculated.

II. The total amount of plant-available N is calculated

IIA. Sources of plant-available N are:
- Mineral fertilizers
- Biological N fixation
- Atmospheric N deposition
- Manure (including N excreted during grazing)
- Nett mineralization of peat soils (because organic matter is oxidized in peat

soil that are drained and used for agriculture)
• Gross mineralization of soils organic matter (all soils)

The N of these sources is not always available for plant uptake (part is rapidly lost as ammonia, part is present as organic N, which become slowly available by mineralization, and part leaches via surface runoff). To estimate the amount of plant-available N a fertilizer N equivalency is introduced. The fertilizer equivalency of fertilizer containing only nitrate and that is applied under conditions without surface runoff is by definition set at 100%. The most common fertilizers containing both nitrate and ammonium and have a somewhat less fertilizer equivalency, because some ammonia volatilization occurs. In table 3.1.5 the fertilizer equivalencies and the made assumptions are presented.

Table 3.15. Fertilizer N equivalencies of different N sources.

N source	Fertilizer N equivalency	Assumptions
Fertilizer: fq_{fert}	100 – NH_3-loss from fertilizer – surface runoff fertilizer, %	
Manure inorganic N: fq_{man}	100 – NH_3-loss from manure – surface runoff manure, %	Assumption: liquid manures contain 60% mineral N, solid manures contain of 25% and excretions during grazing 50%.
Grazing: inorganic : fq_{ex}	80 - NH_3-loss from grazing – surface runoff grazing, %	Assumption that N concentration in urine patches exceed locally the N uptake capacity of the grass, by which a part (20%) is not plant-available, i.e. in winter.
Biological N deposition: fq_{biol}	100% of total fixed N	
Atmospheric N deposition: fq_{atm}	75 % of total deposited N	Assumption that on average 25% of the N is deposited in period with no crop uptake, i.e. in winter
Gross mineralization of soil organic N in mineral soils: fq_{min}	For grassland: 90% from the gross mineralization of organic N in mineral soils. For arable land: 70% from the gross mineralization of organic N in mineral soils. Gross mineralization = N in crop residue in 2000 + organic N in manure + organic N excreted during grazing	Assumption: the gross mineralization is equal to the organic N added via crop residues, manure and grazing in a steady state situation (no change in organic N content of the soil). The amount of crop residue is fixed at the amount in 2000 to facilitate calculation of yield in dependency of the amount of plant-available N. It is assumed that on average 25% of the N is mineralized in period with no crop uptake.

IIB. The total amount of plant-available N =
fertilizer * fq_{fert} + manure N * fq_{man} + excretion during grazing * fq_{ex} +
biological N deposition * fq_{boil} + atmospheric N deposition * fq_{atm} + gross mineralization organic matter * fq_{min}

III. Balanced N fertilization

IIIA. For a balanced N fertilization: the total supply of plant-available N is equal to the total N demand of the crop. If the amount of plant-available N is smaller than the N demand of the crop, the crop yield may decline in time, but the risk of N leaching decreases. In the Nitrate Directive, balanced N fertilization must be achieved, which means that the total amount of plant-available N must be equal to the total N demand of the crop.

The crop N demand is calculated as the total N content of the crop (=harvested part + crop residue) times an efficiency factor. Crops are not able to take up all N in the soils, because of limited density of roots in the soil. It is assumed that on average 25% more available N must be present in the soil than the amount of N in the harvested crop and crop residue. This factor differs between crops (different rooting systems) and regions (different soils and growing conditions), but as a first approach one efficiency factor is used. However, there is scope to refine this efficiency factor and use crop-specific efficiency factors.

In the scenarios the yield is calculated from the amount of plant-available (see paragraph 3.2.3).

IIIB. If the amount of plant-available N is higher than the crop demand, less N must be applied in order to achieve balanced N fertilizer application. The first step is to decrease the N fertilizer input. However, most farmers always will apply some fertilizer and they will not only apply manure (e.g. because they do not have the equipment, manure is not easily available, they are afraid of seeds of weed in manure, can not apply manure on wet soils with heavy machinery etc.). The following "manure acceptance" factor are assumed:

- For fodder production (including grassland) the minimum application rate fertilizer N amounts to 0% of the fertilizer application in 2000, i.e. it is possible that these crops are only fertilized with manure.
- For all other crops: the minimum application rate fertilizer N is arbitrary set to 50% of the fertilizer application in 2000. Many of these crops are not fertilized with manure (the growth of these crops are independent of livestock systems), so that it not likely that the amount of applied manure in these crops will strongly increase after implementation of the Nitrates Directive.

If a balance N fertilization is still not achieved after a reduction of N fertilizer, the application rate of manure N is reduced. The excess manure is treated and removed from agriculture. In this situation, manure is produced and stored, but not applied to soils. There is still emissions and leaching of N, but this removed manure does not induce emission and leaching from soils.

It must be noted that the used definition of balanced N fertilization is strict and asks for good management skills of the farmer.

<u>Maximum manure N application rate</u>

The total amount of manure N (including excretion during grazing) may not exceed 170 kg N/ha or the value for derogation (e.g. 250 kg N per ha for grassland in the Netherlands and 230 for Denmark).

The following approach is chosen:

For situations without a derogation:

- The total amount of soil-applied manure and N excreted during grazing is calculated per NUTS 2 region.
- The average manure application rate in kg N per ha agricultural land is calculated per NVZ.
- If the average amount exceeds 170 kg N per ha, manure is transported to other NUTS 2 regions in the specific country (=evenly distributed over the other NUTS 2 regions).
- If there is an excess (i.e. if the average manure production in a country is higher than 170 kg N per ha), the remaining manure is treated and removed from agriculture. In this situation, manure is produced and stored, but not applied to soils. There is still emissions and leaching of N, but this removed manure does not induce emission and leaching from soils.
- The change in manure application in a NVZ is counterbalanced with mineral N fertilizer, on basis of fertilizer equivalencies (see above). So the amount of plant-available N remains equal. Ideally, this measure is combined with the measure of balanced N fertilizer application.

In situation with a derogation:

Because the derogation is country-specific, also calculations are country-specific. In the beginning of 2006, two countries had a derogation: Denmark and the Netherlands. These derogation are included in MITERRA-EUROPE. In 2006, derogations were granted to Austria (up to 230 kg N per ha from livestock manure in cattle farms) and Germany (up to 230 kg N per ha from livestock manure in cattle farms on intensive grassland). These derogation are not included in MITERRA-EUROPE, because they were granted in the period that MITERRA-EUROPE was developed. However, there is a general rule for derogation included in MITERRA-EUROPE (see below). Possibly, the number of countries with a derogation increases in the future.

Denmark
Denmark has a derogation for 230 kg N per ha manure N (including N excreted during grazing) for farms at which the area with crops with a high N demand is larger than 70 percent. These crops include grassland, fodder beet, and grass as winter crop. The derogation only applies to about 5% of agricultural soils in Denmark and to about 6% of the total N in animal manures. The derogation is limited to existing grassland farmers and the milk quota will limit extensions to other areas.

In MITERRA-EUROPE the following assumptions and calculations are made:
- the 5 percent of the agricultural area is evenly distributed over NUTS 2 regions
- the derogation of 230 kg N per ha applies only for grassland

The Netherlands
In the Netherlands farms with a least 70% grassland can apply for a derogation of 250 kg manure N per ha. The derogation only applies for manure from grazing animals, especially dairy cattle. The remaining part is mainly silage maize. It is assumed that farms that apply for a derogation have on average 80% grassland and 20% maize. This would mean that if at all grasslands 250 kg N per ha is applied, also 250 kg N per ha can be applied at maize at an area of 0.20*total grassland area. However, the extensively managed farms will not apply for a derogation, so only on part of the grassland (and maize land) 250 kg N per ha is applied. At the remaining part, less than 170 kg N per ha is applied.

In the derogation request, it was expected that around 25,000 farms (from a total of 75,000 farms in the Netherlands), covering around 900,000 ha of agricultural area (from a total of 2,000,000 ha), will apply for a derogation. If it assumed that this is covered by 80% grassland and 20% maize land, the total area of grassland in the Netherlands to which 250 kg N per ha is applied is 720000 ha (72% of grassland area) and this means that at 180.000 ha maize land (90% maize land area 250 kg N per ha is be applied.

It assumed that application of derogation is equal for all soil types and NUTS 2 regions, so that at 72% of the grassland area and at 90% of the maize land area of NUTS 2 regions 250 kg manure N can be applied. The manure application rate in the other part of the agricultural area should be less or equal to 170 kg N per ha.

The calculations (including distribution of excess manure over NUTS 2 regions) are the same as for the situation without derogation.

Other countries
For a prediction of a full implementation of the Nitrate Directive, assumptions must be made of derogation request for other countries. The following assumptions are made in MITERRA-EUROPE:
- only countries with NUTS 2 regions in which the average manure application (including N excreted during grazing) is higher than 170 kg N per ha apply for a derogation.
- It is assumed that a derogation is only given for grassland, because of its high N uptake capacity.
- It s assumed that a derogation is only given for the NUTS 2 regions in which manure application rate is higher than 170 kg N per ha.
- It is assumed that the derogation applies to only 50% of the grassland within the NUTS 2 regions in which manure application rate is higher than 170 kg N per ha.
- The total application rate of manure on grassland with derogation is 250 kg N per ha.

No fertilizer and manure application in winter and wet periods

The availability of manure N for crops (fertilizer equivalency) increases, so that the amount of required N fertilizer decreases. It is assumed that 25% of the manure is applied in winter and that 50% of the N in this manure is plant-available when it is applied in spring.

Limitation to fertilizer application on steeply sloping grounds

The measure is only applicable for the area within a NUTS 2 region or NVZ with a certain slope class:
- Steep slope: 50% reduction of N fertilizer and manure in comparison to application rate in 2000 in that area;
- Intermediate: 25% reduction of N fertilizer and manure in comparison to application rate in 2000 in that area;
- Slight 5% reduction of N fertilizer and manure in comparison to application rate in 2000 in that area;
- No reduction.

Manure storage with minimum risk on runoff and seepage

After fully implementation of this measure it is assumed that:
- All liquid manure storages without concrete floor are converted into liquid storage with concrete floor;
- 50% of solid manure storages without concrete floor are converted into solid storage with concrete floor;
- 50% of solid manure storages without cover are converted into solid storage with cover.

Appropiate fertilizer and manure application techniques, including split application of N

This technique leads to a higher efficiency of applied N and a lower leaching below rooting zone. It assumed that after full implementation of this technique (all crops) that the leaching fraction below rooting zone decreases with 10%.

Buffer zones near water courses

Buffer zones near water courses decrease leaching and surface runoff to the surface water. The effectiveness of the buffer zone depends on the slope of the soil, width of the buffer zone, hydrology, crop type (in and outside the buffer zone), soil type. A study has been carried out on behalf of the European Commission - DG Environment entitled “Assessment of Action Programmes Established by Member States under Directive 91/676/EEC”. Some findings of this study are:
- the reduction by the buffers strip of the sediment component in runoff water varied between 23% and 97% in one study;

- the retention of nutrients in buffer zones wider than 10m is often higher than 50%;
- the percentage attenuation levels in runoff from plots were cattle slurry was spread was greater than 90%;
- In the USA, it is considered that buffer strips take up to 50% or more of nutrients.
- A 6 meters strip reduced water movement by 43-87%, rising to 85-99% with strips of 18 meters. Suspended solids were also trapped - up to 99%.

Moreover, in this study the following general rules in order to size the buffer strip properly were presented:
- For diffuse runoff originating on relatively short slopes (up to about 100m), buffer zones of about 10 meters should be sufficient to obtain a high removal efficiency;
- for diffuse runoff originating over larger areas (and where runoff is not concentrating over one area), buffer zones of about 20 meters will be necessary;
- if the runoff concentrates over one specific are (i.e. at an angle), buffer strip of 10-20 meters long should be installed.
- If a buffer zone is created along a river, it is advisable to design it in such a way that the field-side remains straight.

In this study, it was also mentioned that the larger the water body to be protected the larger the buffer zone required, and the larger the buffer zone Catchment area, the wider the buffer zone required.

In MITERRA-EUROPE only buffer zones of 100 meter in riparian zones near large surface waters in agricultural regions are considered, because there are no data of the presence of small surface waters. Large surface water is here defined as the surface water which is present on the CCM River and Catchment Database, version 1.0 (Vogt et al., 2003; see table 3.10). This data base has a resolution of 250x250 meter. Small surface water such as ditches and creeks are not accounted for in the CCM Database and not included in MITERRA-EUROPE.
The following assumptions are made for a 100 meter buffer zone.
- The buffer zones are not fertilized with fertilizer and manure and are not grazed. N fixation can occur.
- Reduction of runoff fraction: 50%
- Reduction of leaching to surface water 50%
- The remaining part of N is denitrified. It is assumed that 10% of the extra denitrification is emitted as N_2O.

It must be mentioned that the effect of buffer strips is strongly dependent on many factor, including soil type, vegetation/crop, weather conditions, and hydrology. The assumed effects of buffer strips should be considered as first estimate in MITERRA-EUROPE, but need to be underpinned and improved. This was not possible within this project. It is assumed that fallow and set-aside land are moved to the buffer zone area, so that net no change in the total agricultural land occurs.

Growing winter crops

Growing winter crops will result in i) less N leaching below rooting zone, ii) less surface run-off, and iii) less requirement of fertilizer N in the following year. However, it is not possible to grow winter crops after all arable crops (because of late harvest times or other crop management aspects).
The following assumptions are made:

- winter crops can be grown after 25% of the arable crops;
- winter crops reduce the fractions of N leaching from rooting zone with 25%;
- winter crops reduce the surface runoff fractions with 25%;
- in intensive NUTS 2 regions (i.e. with an average N surplus > 100 kg N per ha), the N fertilizer application can be reduced with 25 kg N per ha per year after growing winter crops.

In Central/East Europe and Scandinavian countries the figures are different, because of the cold conditions in winter

- after 15% of the arable crops in a NUTS 2 region, winter crops can be grown;
- winter crops reduce fraction N leaching from rooting zone with 10%;
- winter crops reduce surface runoff fraction with 10%;
- in intensive NUTS 2 regions (i.e. with an average N surplus > 100 kg N per ha), the N fertilizer application can be reduced with 10 kg N per ha per year after growing winter crops.

4 Scenarios

In table 4.1 an overview of the 4 RAINS scenarios and 4 Nitrate Directive scenarios that have been assessed in task 1 of the Service Contract (see Chapter 5).

Table 4.1 RAINS and Nitrate Directive (ND) Scenarios.

Name of scenario	Description
RAINS A 2000 RAINS A 2010 RAINS A 2020	These are the NEC_NAT scenarios for 2002, 2010, and 2020 from Amann et al. (2006). For these scenarios, most Member States provided official national projections of their agricultural activities up to 2020 as a basis for the revision of the NEC directive. These projections reflect national agricultural policies and include all necessary measures to comply with the Kyoto targets on greenhouse gas emissions. For those Member States that have not provided their own agricultural projection, the "National Projections" baseline case assumes by default the agricultural development as outlined by the CAPRI, EFMA or FAO.
RAINS optimized	Optimized emission reduction, i.e. implementation of the most cost-effective sets of measures, so that the targets of the Thematic Strategy in 2020 are met (Amann et al., 2006).
ND partial 2000 ND partial 2010 ND full 2020	The implementation of measures of the ND action programmes and the Codes of Good Agricultural Practice in EU-15 in 2000 was estimated by the authors using results from another service contract[2]. The measures had to be translated and simplified for input into MITERRA-EUROPE. In the other member states, the Nitrate Directive was not year implemented in 2000. The estimated implementation of the different measures in 2000 and 2010 are presented in tables 4.2 and 4.3. For 2010 it assumed that for the new member states most measures are implemented at 25% of the NVZ area. For the other member states, implementation rate of measures are estimated using the implementation rate of 2000 and expected implementation rate of 100% in 2020. For the scenario with full (strict) implementation in 2020, it is assumed that all measures of table 4.2 are 100% implemented in Nitrate Vulnerable Zones (NVZ). The area of NVZ will increase, as estimated by Joint Research Centre (see Annex 1). For 2020, a larger area of NVZ is included in the model. It must be clearly mentioned that the implementation rates of the measures were not evaluated by the member states, so that deviations between the estimated implementation in MITERRA-EUROPE and the real implementation can not be excluded.
Water Framework Directive (WFD)	For the WFD scenario, it was assumed that the measures of the Nitrate Directive were 100% implemented in Nitrate Vulnerable Zones in 2020 (scenario ND full 2020) and that on national level equilibrium of P fertilization is achieved. It must be mentioned, that the targets and measures in the WFD have to be set, but it is likely that the packages of measures to be taken for the WFD differ from those taken in the present study. E.g. the measures in the WFD may differ between river basins and probably include hydrological measures, besides N and P measures.

2 IMPLEMENTATION OF COUNCIL DIRECTIVE 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources, Contract 2005/409860/MAR/B1.

Table 4.2. Assumed implementation of measures in Nitrate Vulnerable Zones (see figure 3.2 and Annex 1) in 2000 and 2010, in % (100% = full implementation).

Year	Country	Balanced N application	Max. animal manure application	application in winter and wet conditions	limitation on steeply sloping soil	low leaching manure storage	application techniques	bufferstrips	wintercrops
2000	Austria	25	0	50	50	0	0	0	0
2010	Austria	50	100	75	75	50	50	50	50
2000	Belgium	25	0	50	50	0	25	25	0
2010	Belgium	35	25	75	75	25	35	35	25
2000	Bulgaria	0	0	0	0	0	0	0	0
2010	Bulgaria	50	100	25	25	50	50	50	50
2000	Cyprus	0	0	0	0	0	0	0	0
2010	Cyprus	25	25	25	25	25	25	25	25
2000	Czech Rep.	0	0	0	0	0	0	0	0
2010	Czech Rep.	25	25	25	25	25	25	25	25
2000	Denmark	25	0	50	50	100	25	25	100
2010	Denmark	50	100	50	75	100	50	35	50
2010	Espagne	25	25	25	25	25	25	25	25
2000	Estonia	0	0	0	0	0	0	0	0
2010	Estonia	35	25	75	75	100	35	75	35
2000	Finland	25	0	50	50	100	25	50	25
2010	Finland	35	25	35	75	75	35	25	35
2000	France	25	0	50	50	0	25	25	0
2010	France	50	100	75	75	25	50	75	50
2000	Germany	25	0	25	50	50	25	0	25
2010	Germany	50	100	75	75	25	50	75	50
2000	Greece	25	0	50	50	0	25	50	0
2010	Greece	50	100	25	25	25	50	50	25
2000	Hungary	0	0	0	0	0	0	0	0
2010	Hungary	50	100	50	50	25	50	35	50
2000	Ireland	25	0	25	25	0	25	50	25
2010	Ireland	25	25	50	25	25	50	50	50
2000	Italy	0	0	25	50	0	25	25	25
2010	Italy	25	25	25	25	25	25	25	25
2000	Latvia	0	0	0	0	0	0	0	0
2010	Latvia	25	100	75	75	25	25	50	25
2000	Lithuania	0	0	0	0	0	0	0	0
2010	Lithuania	25	25	25	25	25	25	25	25
2000	Luxembourg	0	0	50	50	0	0	25	0
2010	Luxembourg	35	25	75	75	100	35	25	25
2000	Malta	0	0	0	0	0	0	0	0
2010	Malta	50	100	25	25	25	50	25	25
2000	Netherlands	25	0	50	50	100	25	0	0
2010	Netherlands	25	25	25	25	25	25	25	25
2000	Poland	0	0	0	0	0	0	0	0
2010	Poland	25	25	25	25	25	25	25	25
2000	Portugal	0	0	0	0	0	0	0	0
2010	Portugal	25	25	25	25	25	25	25	25
2000	Romania	0	0	0	0	0	0	0	0
2010	Romania	50	100	25	50	25	25	25	25
2000	Slovakia	0	0	0	0	0	0	0	0
2010	Slovakia	50	100	25	50	25	25	25	25
2000	Slovenia	0	0	0	0	0	0	0	0
2010	Slovenia	25	25	25	25	25	25	25	25
2000	Spain	0	0	0	0	0	0	0	0
2000	Sweden	25	0	50	25	0	0	0	0
2010	Sweden	35	25	75	35	25	25	25	25
2000	United Kingdom	25	0	50	50	0	0	25	25
2010	United Kingdom	50	100	75	75	25	25	50	50

5 Results and discussion

5.1 Comparison ammonia emission of RAINS and MITERRA-Europe

There is a good agreement in the ammonia emissions in 2000 calculated with MITERRA-EUROPE and those calculated with RAINS (Figures 5.1 and 5.2, Annex 2). This is because MITERRA-EUROPE uses the same animal number, N excretions, emission factors and implementation of ammonia abatement techniques. The slight difference in ammonia emission from manure is caused by the fact that in MITERRA-EUROPE also leaching and denitrification (as N_2) losses from manure in housing and storage is calculated, so that less manure N is applied to the soil. For mineral fertilizer, the slight differences in ammonia emission are due slight differences in the amount of applied N fertilizer (Annex 2).

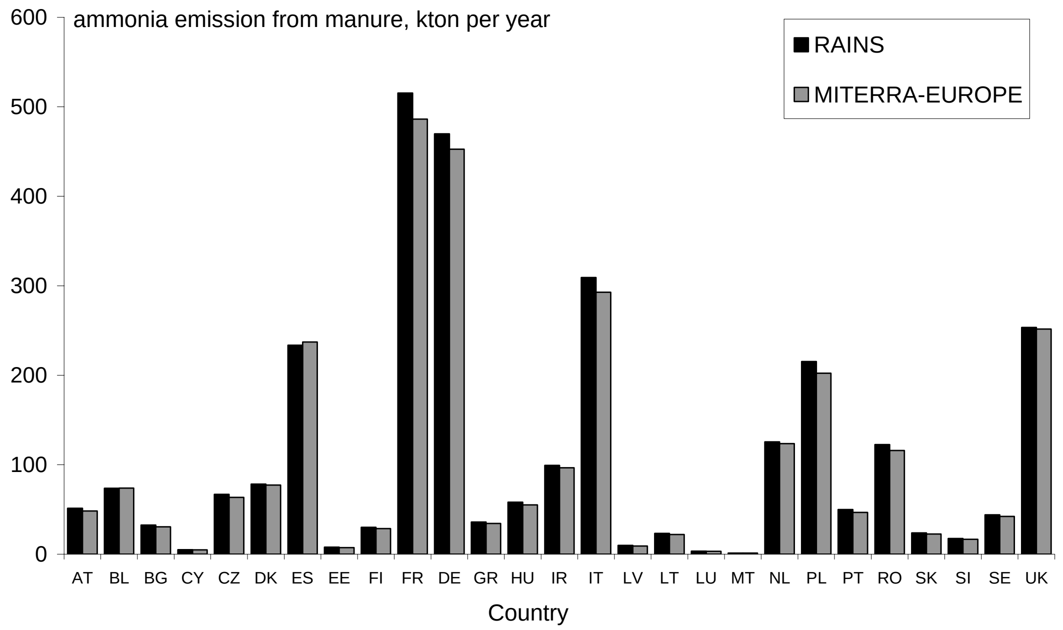


Figure 5.1. Ammonia emission from manure (housing, storage, and soil) in 2000 calculated with MITERRA-EUROPE and RAINS.

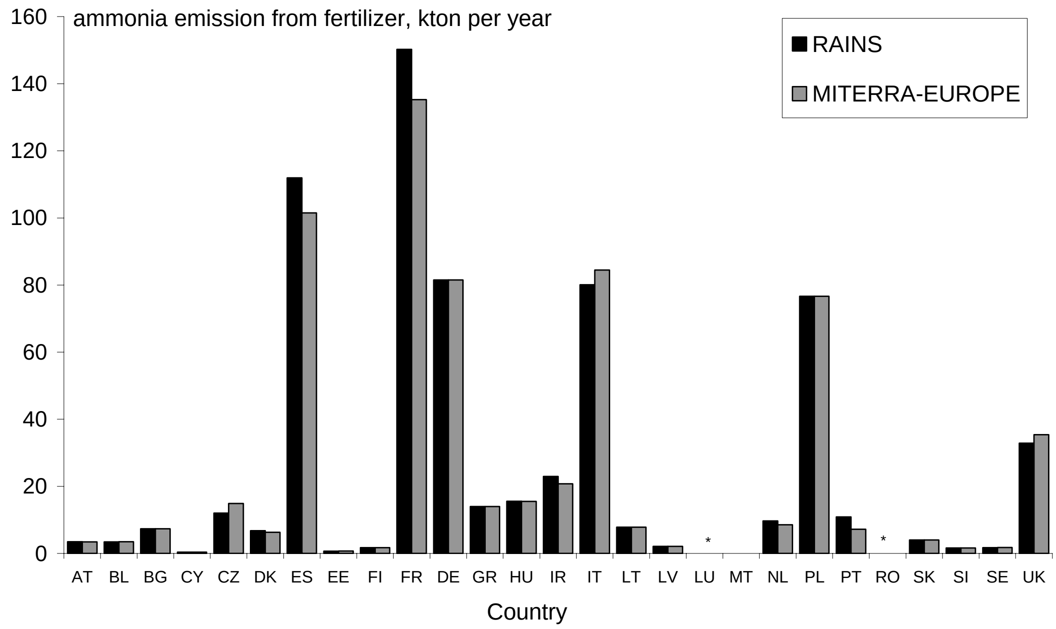


Figure 5.2. Ammonia emission from mineral N fertilizer in 2000 calculated with MITERRA-EUROPE and RAINS.

5.2 Single measures

In Figure 5.3 the potential effects of single measures are presented, i.e. the effect of full implementation compared to a situation without any measures (using activity data of 2000). The implementation of single abatement technologies for NH_3 emissions can lead to slight increases in the leaching of NO_3 and the emissions of N_2O, when no supplemental measures are taken to correct for the increased N contents of the animal manure (Figure 5.3 and table 5.1). Possible increases in yields because of higher N contents in manure due to ammonia abatement are included in the model. This increase in yield, decreases the risk on pollution swapping and especially that on increases NO_3 leaching. However, when the last (but not least) measure of the guidelines of the UNECE Working Group on Ammonia Abatement Technologies is taken into account, the increased leaching of NO_3 and the emissions of N_2O will be prevented (see the combination of NH_3 measures and balanced N fertilization in table 5.1). This measure deals with 'Nitrogen management; balancing manure nutrients with other fertilizers to crop requirements' and will lead to a correction in the application rates of animal manure and/or N fertilizer use. This measure is formulated rather general and not implemented in RAINS/GAINS, and hence not shown in Figure 5.3 Greater emphasis should be given to this measure/recommendation of the UNECE Working Group on Ammonia Abatement Technologies so as to prevent the pollution swapping to the leaching of NO_3 and the emissions of N_2O.

All measures taken to decrease N leaching have synergistic effects, i.e. the measures also decrease the emissions of NH_3 and/or N_2O (Figure 5.3 and table 5.1) Effects on CH_4 emissions are absent, and therefore not shown. Balanced fertilization has the largest effects on N leaching losses and also the largest synergistic effects. The package of measures is also highly effective and has the potential of significant synergistic effects. However, it must be mentioned that part of the large effect is due removing of manure from agriculture (treatment of manure), which would have a large economic impact on agriculture. The calculated synergistic effects of some N leaching abatement measures on emissions of NH_3 and/or N_2O may be somewhat too optimistic. This holds especially as regards the ban on manure spreading in autumn and winter. It has been observed in the UK (Williams personal communication) that a ban on manure spreading in autumn and winter, to decrease N leaching losses, may contribute to increased emissions of NH_3 because of the higher temperature and drier conditions in summer and spring compared to autumn and winter in most EU countries. In MITERRA-EUROPE, emissions of NH_3 are calculated following the procedure in RAINS, and are calculated independent of temperature and or rainfall.

At the suggestions of the reviewers and the Commission, new feedbacks were incorporated in MITERRA-EUROPE (coupling N deposition - NH_3 emissions; coupling crop yield – N input; coupling N uptake by the crop – N input). These feedbacks have made the model more robust but also more complex. Because of these feedbacks, the antagonistic effects of some NH_3 emission abatement measures and of some N leaching abatement measures reported here are smaller compared to the effects reported in the draft final report (21 January 2007 version).

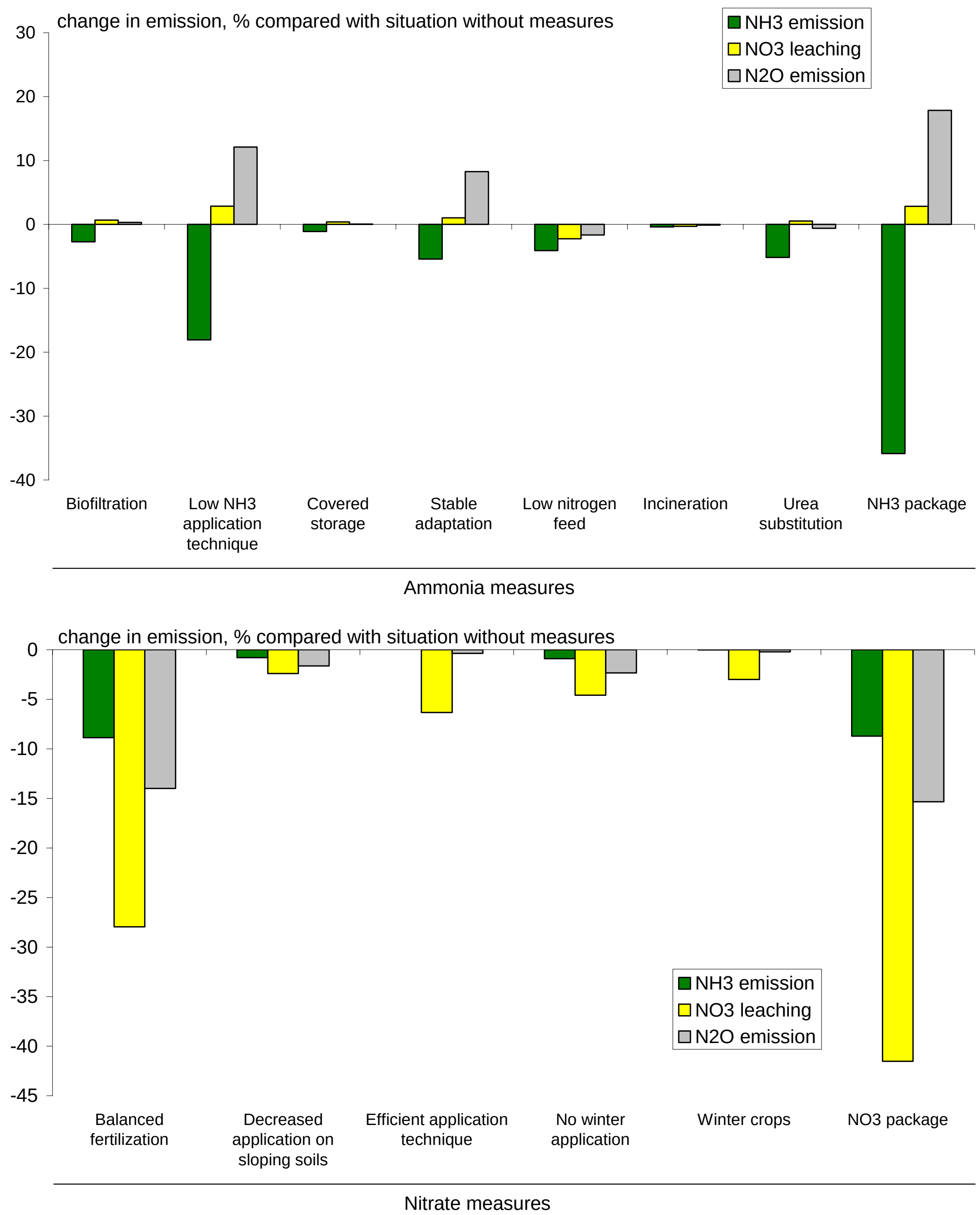


Figure 5.3. Potential or maximum effect of single and a package of ammonia and nitrate measures at full implementation compared to a situation without any measures, based on activity data of EU-27 for 2000 and measures of MITERRA-EUROPE.

Table 5.1 Maximum effects of (packages of) measures on emissions, compared to a situation without measures (with activity data of 2000).

Code	measures	NH_3 emission, change in %	N leaching, change in %	N_2O emission, change in %
A1	Low Nitrogen Fodder	-4.1	-2.3	-1.7
A2	Stable Adaptation	-5.4	1.0	8.3
A3	Covered Manure Storage	-1.1	0.4	0.1
A4	Biofiltration (air purification)	-2.7	0.7	0.3
A5	Low Ammonia Application of Manure	-18.1	2.9	12.1
A6	Urea substitution	-5.2	0.5	-0.6
A7	Incineration of poultry manure	-0.4	-0.3	-0.1
N1	balanced N fertilizer application	-8.9	-28.0	-14.0
N2	Maximum manure N application standard	-0.9	-2.7	-0.4
N3	Limitation to N application in winter and wet periods	-0.9	-4.6	-2.3
N4	Limitation to N application on sloping grounds	-0.8	-2.4	-1.6
N5	Manure storage with minimum risk on leaching	1.1	-5.2	0.3
N6	Appropiate pplication techniques	0.0	-6.3	-0.4
N7	Riparian zones	0.0	-0.4	0.3
N8	Growing winter crops	0.0	-3.0	-0.2
P1	Equilibrium fertilization of P	-8.2	-7.8	-4.4
A1 + N1	Low Nitrogen Fodder + balanced N application	-12.4	-29.1	-15.1
A2 + N1	Stable Adaptation + balanced N application	-14.6	-27.2	-5.9
A3 + N1	Covered Manure Storage + balanced N application	-10.1	-27.7	-14.0
A5 + N1	Low Ammonia Application + balanced N application	-24.4	-26.3	-4.2
N1 + P1	Balanced N and P fertilization	-12.9	-31.5	-16.1
A1-A7	Package of ammonia measures	-35.9	2.8	17.9
N1-N8	Package of nitrate measures	-8.7	-41.5	-15.3
A1-A7 + N1-N8	All ammonia and nitrate measures	-40.7	-40.8	0.3

5.3 Results for the year 2000

A summary of the results on the country and EU-27 level is presented in tables 5.2 and figure 5.4 (total per country). In Annex 3, part of the results are presented in maps with NUTS regions.

Tables 5.2 shows large differences between countries and clearly indicate that countries with high NH_3 emission, also have NO_3 leaching and N_2O emission. Denitrification to N_2 is the largest absolute source of N loss, followed by NH_3, leaching, nitrous oxide emission and NO_X emission (Figure 5.4). However, the environmental impact of the different N emissions differ and small emissions can already can have negative effect on quality of the environment. For example, a small N leaching of a few kg per ha can already result in enhanced algal growth in surface waters.

Countries with a high density of livestock and especially ruminants have highest CH_4 emissions on a hectare bases, such as the Netherlands and Belgium (figure 5.5).

Table 5.2. N inputs and N losses in EU-27 in 2000 in kton.

Country	total N excretion	applied manure	grazing	applied fertilizer	N fixation	N deposition	N yield	N surplus	NH3-N	N2O-N	NOx-N	N2	N leaching				
													manure storage	runoff	large surface waters	groundwater +small surface water	total
EU-27	10,372	4,785	3,560	11,302	823	1,976	10,678	13,795	2,873	324	352	7,486	256	750	115	1,661	2,782
Austria	171	86	50	118	16	64	171	199	43	5	6	121	6	8	0	12	26
Belgium	288	156	78	149	5	43	218	266	64	8	9	111	7	15	4	50	76
Bulgaria	132	51	59	145	13	47	185	151	31	4	6	61	4	27	1	18	50
Cyprus	19	7	8	8	0	1	5	24	4	0	1	15	0	1	0	2	4
Czech. Rep	190	107	37	263	15	37	243	263	64	6	6	100	7	36	1	43	87
Denmark	270	181	34	234	12	46	241	321	69	8	6	155	6	14	3	62	85
Estonia	24	12	6	22	2	7	32	23	7	1	1	9	1	2	0	3	6
Finland	104	59	23	167	7	10	108	180	25	4	3	134	3	4	2	6	14
France	1,798	741	722	2,316	191	437	1,811	2,931	509	60	75	1,738	43	128	16	368	555
Germany	1,371	837	241	1,848	101	160	1,459	2,020	439	44	38	1,065	28	108	17	285	438
Greece	241	52	166	285	12	34	235	337	40	8	9	248	4	9	0	20	34
Hungary	173	89	39	320	17	55	246	319	58	7	5	173	6	28	4	39	77
Ireland	579	187	341	368	17	44	507	500	97	14	29	275	6	22	11	47	86
Italy	880	433	228	828	93	162	862	1,101	310	26	22	549	29	55	5	108	198
Latvia	31	14	9	28	3	15	41	36	9	1	1	16	1	3	1	5	9
Lithuania	75	35	26	98	12	26	132	78	25	2	3	21	2	13	1	11	27
Luxembourg	12	5	5	13	1	3	13	16	3	0	1	7	0	2	0	3	5
Malta	3	2	0	0	0	0	0	4	1	0	0	2	0	0	0	0	1
Netherlands	506	308	121	300	8	68	336	546	108	15	14	273	9	19	15	92	137
Poland	597	337	80	896	49	151	633	1,060	229	24	15	566	24	62	11	132	229
Portugal	157	67	57	113	6	9	116	170	44	4	5	92	5	8	0	12	25
Romania	438	188	166	239	48	141	603	264	111	10	17	71	13	46	1	17	78
Slovakia	71	35	20	82	10	22	132	53	22	2	2	14	2	7	0	4	13
Slovenia	41	25	5	35	2	5	31	51	15	1	1	27	2	2	0	4	8
Spain	887	324	412	1,114	66	121	879	1,309	276	29	38	764	22	61	4	118	205
Sweden	147	76	41	197	11	14	175	194	36	5	5	135	4	2	1	6	14
United Kingdom	1,169	368	583	1,115	106	253	1,263	1,379	235	36	34	744	21	68	14	196	298

In table 5.3 the N surplus on the soil balance[3] calculated with MITERRA-EUROPE in 2000 are compared with those of Eurostat/EEA for 2000 and OECD for 1997. In general, there is a good agreement between the three methods, but for some countries the calculated N surplus with MITERRA-EUROPE is higher (e.g. Finland, Italy) and for some countries lower (e.g. Spain and Portugal) than the other methods. The major differences in calculation of the N surplus between MITERRA-EUROPE and the other methods are:

- The losses in housings and manure storages. MITERRA-EUROPE calculate losses via NH_3, N_2O, N_2 and leaching in housing and storage using country specific emission factors and activity data (e.g.. type of manures), by which the N losses from manure in housings and storage differ between the countries. The other methods use estimates from countries.
- N contents of crops. In paragraph 3.2.3, the method of MITERRA-EUROPE are explained. Eurostat uses estimates from countries.
- Grassland yields. In Eurostat the yields are calculated from the need for feed by animals. The method of MITERRA-EUROPE is explained in paragraph 3.2.3

It is not clear which methods provides the best estimate of the N surplus. The N surplus is an important environmental indicator, which is used in policy, but also for calculations of N emissions from agriculture. There is scope to improve the estimates of the N surplus and to develop a general approach which is less dependent on the direct input of the different countries. A model as MITERRA-EUROPE can be helpful to develop such an approach.

The focus in this service contract was on the development and application of the integrated N model MITERRA-EUROPE. The ammonia results were compared with those of the RAINS model and the other emissions were roughly compared with results of literature. On basis of expert knowledge is was concluded that results were plausible, but it is recommended to carry out an in-depth analyses of the results on both national and NUTS 2 level, using data from literature (e.g. the reports for the Nitrate Directive).

In Figure 5.6, the P balances of 2000 are shown. The difference between the P inputs and the P output is the P surplus. The P surplus is an indicator for the accumulation of P in the soil and P leaching to surface waters. Decreasing the P surplus is generally the first step to decrease risk on P pollution of surface waters. Countries with a high P surplus include Netherlands, Belgium, Ireland, Italy, and Slovenia. In the Netherlands, the aim is to achieve a balanced P fertilization in 2015, i.e. the P input is equal to the P output. Balanced P fertilization can be achieved by decreasing the input of P fertilizers and manure. P fertilizers mostly only contain one nutrient (P), so that decreasing P fertilizer input does not affect N emissions. However, manures contain both N and P and decreasing P input via manure can significantly affect N emissions in case the decrease in manure input is achieved by decreasing number of animals, export of manure, or treatment of manure. Decreasing the P content of the feed is an other option, but this only affects N emissions when also the N contents of the feeds changes.

[3] N surplus on soil balance = applied N fertilizer + applied manure + N excreted during grazing + atmospheric deposition + biological N fixation – N removed via harvested/grazed products

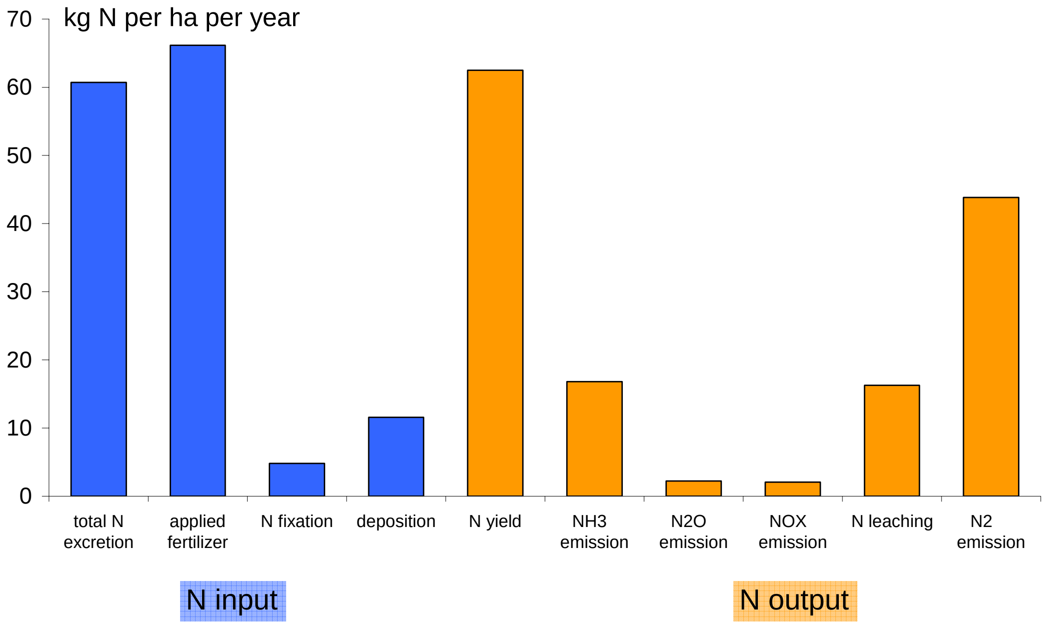


Figure 5.4. Average N balance in EU-27 in kg N per ha per year.

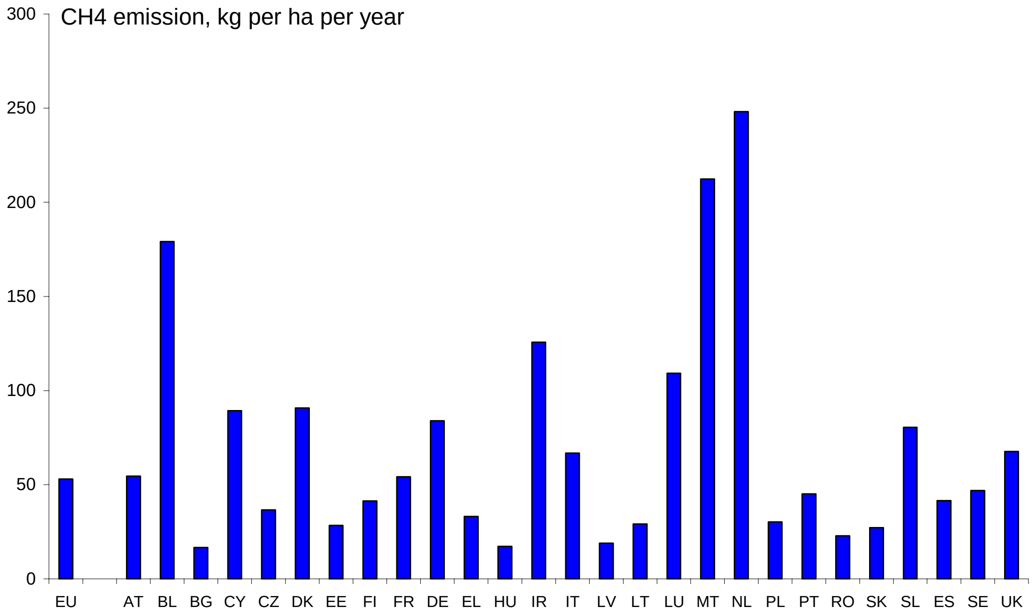


Figure 5.5. CH_4 emissions in kg per ha 2000.

Table 5.3. N surplus on the soil balance (in kg N per ha) calculated with MITERRA-EUROPE (2000) compared with those of Eurostat/European Environmentl Agency (EEA) (2000), and OECD (1997).

	MITERRA-EUROPE 2000	EEA/Eurostat 2000	OECD 1997
Austria	45	43	29
Belgium	158	174	178
Bulgaria	26		
Cyprus	181		
Czech. Rep	58		52
Denmark	104	77	112
Estonia	24		
Finland	78	51	59
France	91	39	51
Germany	108	105	56
Greece	63	69	30
Hungary	49		-17
Ireland	102	44	75
Italy	64	37	29
Latvia	16		
Lithuania	25		
Luxembourg	111	117	
Malta	255		
Netherlands	248	226	248
Poland	58		30
Portugal	43	42	62
Romania	13		
Slovakia	17		
Slovenia	79		
Spain	57	39	44
Sweden	58	38	36
United Kingdom	65	45	87

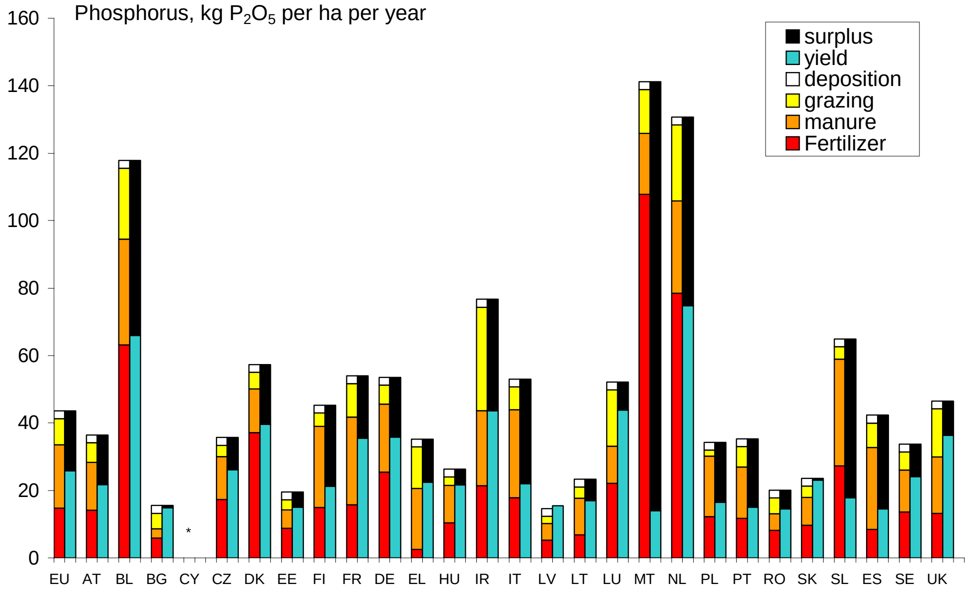


Figure 5.6. Phosphorus balance (kg P_2O_5 per ha per year) in 2000. Inputs are fertilizers, manure, excretion during grazing, and atmospheric deposition. The yield is the output.

5.4 Results of the RAINS scenarios

Figure 5.7 provides an overview of the changes in the emissions of NH_3, N_2O and NO_X and the leaching of N in the RAINS scenarios. Decreases are larger in the emissions of NH_3 than the emissions of N_2O and NO_X and the leaching of N.

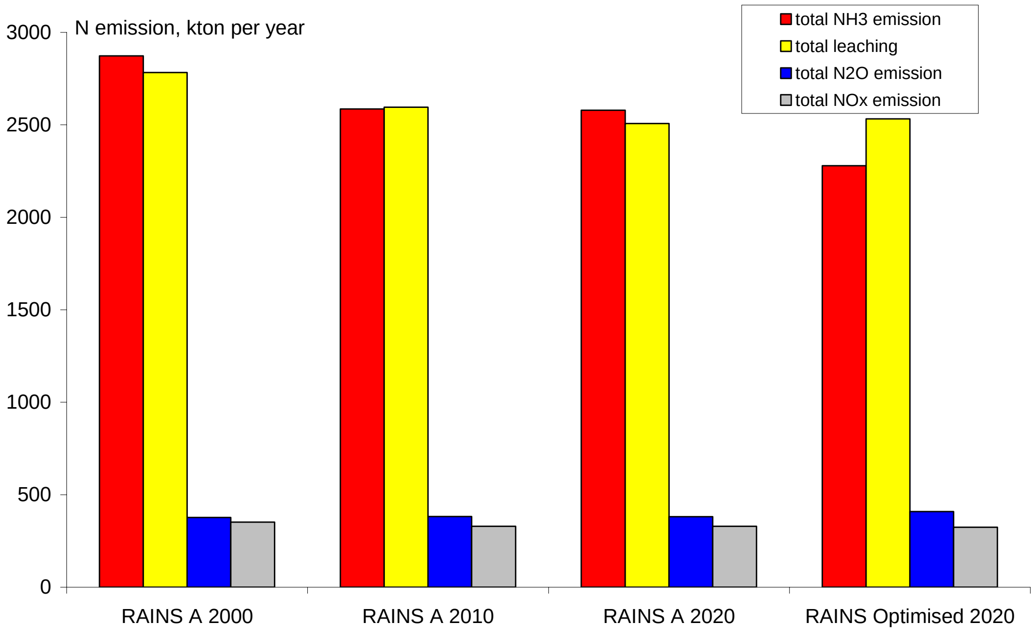


Figure 5.7. Gaseous N losses and N leaching losses from agriculture in the RAINS A 2000, 2010 and 2020 scenarios and in the RAINS optimized 2020 scenario.

Total NH_3 emissions in EU-27 in the year 2020 are 10 and 21% lower than in 2000, according to the RAINS A 2020 and RAINS optimized 2020 scenarios, respectively (Table 5.4). The MITERRA-EUROPE calculated NH_3 emissions in the RAINS A scenarios for 2000 and 2020 compare well with the RAINS calculated emissions presented in Table 5.4 (Amann et al., 2006). However, the estimated decrease in NH_3 emissions in the RAINS optimized 2020 relative to the RAINS A 2000 scenario according to MITERRA-EUROPE is less (~21%) than the percentage decrease calculated by RAINS (~29%). The cause of this difference is not yet clear.

The RAINS A and RAINS Optimized 2020 scenarios also lead to a considerable decrease (~ 10%) in the leaching of N to groundwater and surface waters (Table 5.5) and in the emissions of CH_4 (Table 5.7), but not in the emissions of N_2O (Table 5.6). The decreases in N leaching are mainly related to the decreases in N fertilizer use and N excretion by animals (because of fewer animals). The estimated increase in the emissions of N_2O in the RAINS optimized 2020 is likely related to the changes in the animal manure management (low-emission manure application techniques increase N_2O emission).

Table 5.4. Ammonia emission in 2000 for EU-27 in kton NH3 and the calculated changes relative to 2000 for the RAINS A 2010 and 2020 scenario and the RAINS optimized 2020 scenario

Country	RAINS A 2000	RAINS A 2010	RAINS A 2020	RAINS optimised 2020
	kton NH3	% change compared to RAINS A 2000		
EU-27	3488	-10	-10	-21
Austria	52	-3	1	-22
Belgium	77	0	-3	-8
Bulgaria	38	-14	-11	-11
Cyprus	5	-12	-11	-28
Czech. Rep	78	-8	-10	-16
Denmark	83	-11	-15	-37
Estonia	8	7	11	1
Finland	30	-13	-24	-31
France	618	-8	-8	-26
Germany	534	-19	-22	-25
Greece	48	-14	-16	-31
Hungary	70	-4	7	-11
Ireland	117	-19	-27	-36
Italy	376	-5	-6	-14
Latvia	11	11	12	-14
Lithuania	30	-1	6	-12
Luxembourg	3	-6	-9	-29
Malta	1	63	75	75
Netherlands	132	-18	-6	-14
Poland	278	1	1	-8
Portugal	53	-9	-10	-27
Romania	135	-4	-4	-4
Slovakia	27	-3	1	-6
Slovenia	18	5	5	-29
Spain	336	-11	-9	-23
Sweden	44	-7	-6	-7
United Kingdom	285	-19	-18	-26

Table 5.5. Total N leaching in 2000 for EU-27 in kton N and the calculated changes relative to 2000 for the RAINS A 2010 and 2020 scenario and the RAINS optimized 2020 scenario.

Country	RAINS A 2000	RAINS A 2010	RAINS A 2020	RAINS optimised 2020
	kton N	% change compared to RAINS A 2000		
EU-27	2782	-7	-10	-9
Austria	26	-14	-11	-10
Belgium	76	-1	-4	-4
Bulgaria	50	-13	-19	-19
Cyprus	4	6	5	6
Czech. Rep	87	10	-1	0
Denmark	85	-19	-26	-23
Estonia	6	18	-9	-7
Finland	14	-16	-27	-27
France	555	-7	-9	-7
Germany	438	-8	-14	-13
Greece	34	-21	-22	-21
Hungary	77	23	24	25
Ireland	86	-34	-47	-46
Italy	198	1	-2	0
Latvia	9	26	8	9
Lithuania	27	17	-3	0
Luxembourg	5	-9	-13	-12
Malta	1	79	88	88
Netherlands	137	-25	-6	-13
Poland	229	4	-2	-2
Portugal	25	2	2	6
Romania	78	6	-4	-4
Slovakia	13	35	13	14
Slovenia	8	3	-7	-2
Spain	205	-7	-8	-5
Sweden	14	-10	-10	-10
United Kingdom	298	-19	-20	-20

Table 5.6. Nitrous oxide emission in 2000 for EU-27 in kton N_2O-N and the calculated changes relative to 2000 for the RAINS A 2010 and 2020 scenario and the RAINS optimized 2020 scenario.

Country	RAINS A 2000	RAINS A 2010	RAINS A 2020	RAINS optimised 2020
	kton N	% change compared to RAINS A 2000		
EU-27	377	2	1	8
Austria	5	-10	-11	5
Belgium	9	1	-1	3
Bulgaria	5	-6	0	0
Cyprus	0	29	32	44
Czech. Rep	8	18	22	27
Denmark	9	-2	-5	5
Estonia	1	15	14	20
Finland	5	-10	-21	-15
France	70	1	0	14
Germany	52	1	-3	-2
Greece	8	-10	-10	-3
Hungary	8	35	44	61
Ireland	16	-17	-24	-20
Italy	31	7	5	10
Latvia	1	18	18	39
Lithuania	3	12	18	31
Luxembourg	0	-6	-9	2
Malta	0	59	69	69
Netherlands	17	-11	1	-2
Poland	28	6	7	11
Portugal	5	16	16	39
Romania	12	14	20	20
Slovakia	2	29	32	37
Slovenia	1	1	0	20
Spain	33	5	5	19
Sweden	6	-2	-1	-1
United Kingdom	40	-6	-5	-1

Table 5.7. Methane emission in 2000 for EU-27 in kton CH_4, and the calculated changes relative to 2000 for the RAINS A 2010 and 2020 scenario and the RAINS optimized 2020 scenario. .

Country	RAINS A 2000	RAINS A 2010	RAINS A 2020	RAINS optimised 2020
	kton CH4	% change compared to RAINS A 2000		
EU-27	9848	-8	-10	-10
Austria	181	-9	-10	-10
Belgium	249	-4	-9	-9
Bulgaria	89	-14	-14	-14
Cyprus	13	1	1	1
Czech. Rep	142	-7	-7	-7
Denmark	237	-3	-8	-8
Estonia	22	-1	-5	-5
Finland	90	-14	-36	-36
France	1558	-6	-6	-6
Germany	1372	-11	-17	-17
Greece	201	-2	-2	-1
Hungary	101	-5	8	8
Ireland	550	-17	-25	-26
Italy	986	-4	-7	-6
Latvia	30	0	-3	-3
Lithuania	81	-8	-10	-10
Luxembourg	13	-7	-15	-15
Malta	2	2	2	2
Netherlands	479	-12	-6	-6
Poland	517	-7	-10	-10
Portugal	176	9	3	3
Romania	339	-4	-4	-4
Slovakia	61	5	5	6
Slovenia	41	5	6	6
Spain	1028	-1	0	0
Sweden	142	-6	-6	-6
United Kingdom	1146	-23	-23	-23

5.5 Results of the Nitrates Directive scenarios

In this paragraph, the results of the two Nitrate Directive scenarios are presented, i.e. partial implementation in 2000 and full implementation (based on activity data of 2000). Note that in some countries the area of Nitrate Vulnerable Zones is very small (Figure 3.2 e.g. Poland, and Spain). Therefore, implementation of the Nitrate Directive in these countries also has small effects on emissions. In new member states (Bulgaria and Romania) no Nitrate Vulnerable Zones are yet designated, by which implementation of the Nitrate Directive does not change emissions in these countries.

Measures of the Nitrates Directive focus on decreasing N leaching, mainly through improved management of N fertilizer and animal manure. Various good agricultural practices have been defined (table 4.2). A prime measure is balanced fertilization, i.e., N application is adjusted to the N demand by the crop and the native N supply by soil and atmosphere. As a consequence, N input via N fertilizer and animal manure may have to be adjusted in some cases, depending on the degree of implementation. Indeed, Tables 5.8 and 5.9 show that the Nitrates Directive scenarios have a large effect on the N input via fertilizer and animal manure in countries en in Nitrate Vulnerable Zones. It is assumed that this decrease in manure N is brought about by a combination of low-protein animal feeding and manure treatment (see below). The Water Framework Directive (WFD 2020) has in addition a large effect on the input of P fertilizer (Table 5.9).

The changes in N input and the application of Good agricultural practices and balanced fertilization have a large effect on the leaching of N from agriculture (Table 5.10). The potential decrease N leaching in the ND full and WFD scenarios is ~30% in EU-27.

Table 5.8. Main N flows in agriculture in EU-27 in 2000, according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 scenario, the ND full 2020 scenario and the WFD 2020 scenario.

N source	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton N	% change compared to ND partial 2000		
Total N excretion	10372	-5	-5	-5
Applied N fertilizer	10748	-7	-14	-14
Applied manure N	4778	-3	-9	-19
N excreted during grazing	3560	-8	-8	-8
N deposition	1977	-4	-4	-4
Biological N fixation	823	0	0	0

Table 5.9. Main P flows in agriculture in EU-27 in 2000 according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 scenario, the ND full 2020 scenario and the WFD 2020 scenario.

P source	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton P2O5	% change compared to ND partial 2000		
Total P excretion	4248	-6	-7	-7
Applied P fertilizer	3476	0	0	-64
Applied manure P	2769	-6	-14	-24
P excreted during grazing	1441	-9	-11	-11

Table 5.10. Total N leaching losses from agriculture to groundwater and surface waters in EU-27 according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 scenario, the ND full 2020 scenario and the WFD 2020 scenario.

Leaching pathway	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton N	% change compared to ND partial 2000		
Manure storage	231	-9	-31	-31
Surface runoff	733	-5	-10	-13
Small surface water and groundwater	1511	-13	-32	-36
Large surface water	103	-17	-36	-40
Total	2575	-11	-26	-29

The implementation of Good Agricultural Practices and balanced fertilization and the decreases in N input via animal manure and fertilizer in the ND full 2020 and WFD 2020 scenarios have also a strong effect on the emissions of NH_3, N_2O, NO_X and CH_4 to the atmosphere. Figure 5.8 provides an overview of the changes in the emissions of NH_3, N_2O and NO_X and the total leaching of N in these scenarios. Decreases are equally large for NH_3 and N_2O emissions and the leaching of N. Decreases in emissions and leaching are large between ND partial 2000 and ND full 2020, but changes ND full 2020 and WFD 2020 are small. The difference between the ND full 2020 and WFD 2020 scenarios is mainly a difference in fertilizer P input (and not in N input; see Table 5.9). Therefore, N emissions do not change (much).

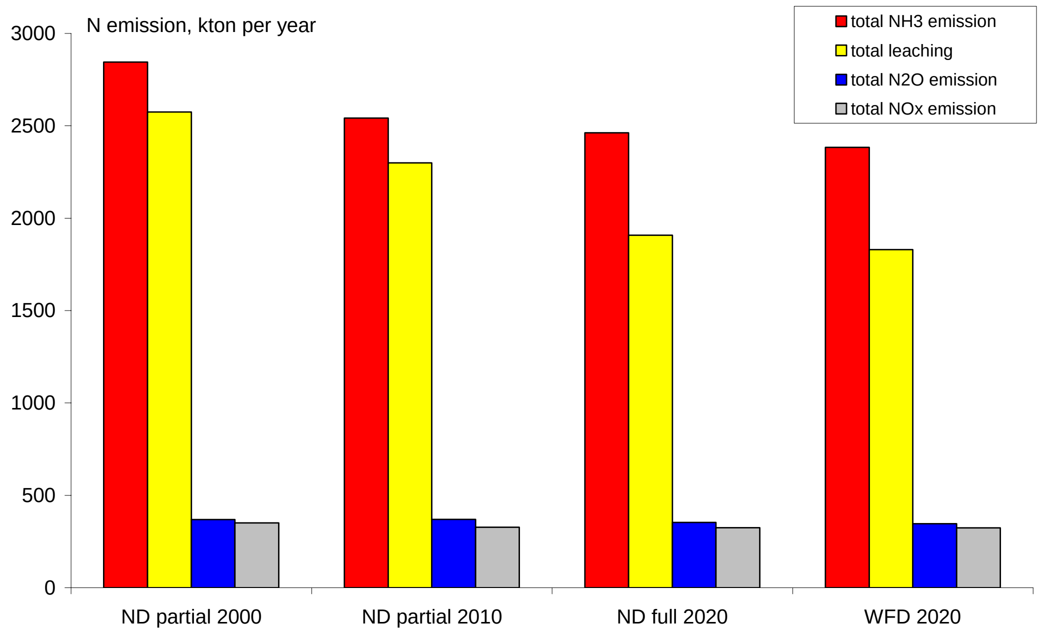


Figure 5.8. Gaseous N losses and N leaching losses from agriculture in the ND partial 2000 and 2010 scenarios, the ND full 2020 scenario and in WFD 2020 scenario.

The emissions of NH_3, N_2O and NO_X and the leaching of N are roughly equal (or slightly less) in the ND partial 2000 scenario than in the RAINS A scenario (compare Tables 5.4-5.7 with Tables 5.11-5.14). Hence, the reference 'ND partial 2000' in this paragraph is similar to the reference 'RAINS A 2000' in the previous paragraph.

Emissions of NH_3 in the ND full 2020 and the WFD 2020 scenarios are 14 and 17 % lower compared to the reference year 2000, respectively. This projected decrease is more than roughly half of the calculated decrease between RAINS optimized 2020 and RAINS A 2000 in Table 5.4. The RAINS optimized 2020 scenario is meant to achieve the objectives of the Thematic Strategy on Air Pollution (TSAP) in 2020. The results of the ND full 2020 scenario suggest that half of the targets of the TSAP for NH_3 emissions may be achieved through full implementation of the Nitrates Directive. However, full implementation of the ND with strict interpretation of Good Agricultural Practices and balanced fertilization may have significant effects for agriculture (Tables 5.8 and 5.9; see below).

Balanced N fertilization requires careful N management. The 'balanced N fertilization' concept in MITERRA-EUROPE is based on a straightforward interpretation of the definition of 'balanced fertilization, i.e.,
Σ (input of available N from all sources) = Σ (N output via harvested crop + crop residues).

This concept was applied to all Member States equally. The amount of 'available N' was derived from the total N inputs of all sources. The uptake efficiency for all crops was set at 25%, i.e. we assumed that the roots of the crops were not able to take up 25% of the calculated amount of available N. The N demand by the crop is derived from the calculated N output via harvested crop + crop residues, and these values are based on country specific yield data for the year 2000. The yield data for most crops have been derived from FAO data statistics. For grassland, yields have been derived from various assessments (see paragraph 3.2.3) We assumed that yields in EU-15 remained constant and that yields in the new Member States in 2020 had increased on average by 15% relative to the yield statistics of 2000. Hence, the concept of balanced fertilization has the target of 'optimal' crop yields (yields do not decrease). In practice though, balanced N fertilization may increase the risk of a crop yield decrease.

Implementation of Good Agricultural Practice, including balanced N fertilization according to the Nitrates Directive, in the ND full scenario suggests that the N fertilizer input will decrease by 22% and that the N input via applied animal manure will decrease by 9% relative to the reference year at EU-27 level. There are however large differences between Member States. Decreasing the N input via animal manure N was assumed to be realised through low-protein animal feeding and/or manure treatment.

The WFD 2020 scenario project even further decreases in the amount of manure N and P to be applied to agricultural land (Tables 5.8 and 5.9). This is because the WFD 2020 scenario includes 'equilibrium P fertilization', in addition to balanced N fertilization. The results indicate that applying this concept will decrease the fertilizer P input by 62%. The input via applied animal manure will decrease by ~21% (Table 5.9). Again, it is assumed that this decrease in animal manure P will be realized through a combination of low-P animal feeding and manure treatment.

As expected, N leaching losses decrease greatly in the ND full 2020 and the WFD 2020 scenarios relative to the ND partial 2000 reference year (Table 5.12). Leaching losses decrease on average at EU-27 level by 29 and 31%, respectively, but there are large differences between Member States. The decrease in N leaching in the ND full 2020 scenario is much stronger than the projected decrease in N leaching according to the RAINS optimized 2020 scenario (Table 5.5), while the latter scenario had a much stronger effect on decreasing NH_3 emissions.

Emissions of N_2O (Table 5.15), CH_4 (Table 5.15) and NO_X (not shown) also decreased in ND full 2020 and the WFD 2020 scenarios relative to the ND partial 2000 reference year. Decreases for all gaseous emissions at EU-27 level were in the range of 8 to10%.

Atmospheric deposition of N decreased by 16 and 17% in the ND full 2020 and the WFD 2020 scenarios relative to the ND partial 2000 reference year. This decrease is related to the decrease in NH_3 emission. Losses via denitrification (as N_2) decreased by 25-28% in the ND full 2020 and the WFD 2020 scenarios relative to the ND partial 2000 reference year (not shown).

Maps on NUTS 2 level (Figure 5.9) point on strong effects of implementation of the Nitrate Directive on N emissions in NW European countries. In the new member states no or small effects are shown, which is due to the small area of NVZ (or absence of NVZ) in these countries, as mentioned before.

Table 5.11. Ammonia emission in 2000 for EU-27 in kton NH_3, according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 and ND full 2020 scenarios and the WFD 2020 scenario.

Country	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton NH3	% change compared to ND partial 2000		
EU-27	3455	-11	-14	-16
Austria	51	-3	0	0
Belgium	76	0	-15	-17
Bulgaria	38	-14	-11	-11
Cyprus	5	-11	-10	-39
Czech. Rep	78	-9	-10	-10
Denmark	82	-11	-17	-17
Estonia	8	7	11	11
Finland	30	-15	-29	-29
France	607	-10	-16	-19
Germany	525	-20	-26	-26
Greece	47	-15	-19	-19
Hungary	71	-5	3	3
Ireland	114	-18	-27	-27
Italy	376	-5	-9	-14
Latvia	11	11	12	12
Lithuania	30	-2	6	6
Luxembourg	3	-6	-10	-10
Malta	1	63	75	-10
Netherlands	132	-20	-14	-20
Poland	278	1	1	0
Portugal	53	-8	-10	-26
Romania	135	-4	-4	-4
Slovakia	27	-3	1	1
Slovenia	18	4	0	-1
Spain	336	-10	-11	-20
Sweden	43	-7	-6	-6
United Kingdom	282	-19	-19	-19

Table 5.12. Nitrogen leaching losses in 2000 for EU-27 in kton N, according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 and ND full 2020 scenarios and the WFD 2020 scenario.

Country	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton N	% change compared to ND partial 2000		
EU-27	2575	-11	-26	-29
Austria	24	-27	-41	-41
Belgium	69	-5	-41	-44
Bulgaria	49	-13	-19	-19
Cyprus	4	6	5	-30
Czech. Rep	85	7	-10	-10
Denmark	65	-20	-37	-37
Estonia	5	21	-11	-11
Finland	10	-27	-51	-51
France	512	-12	-27	-30
Germany	367	-20	-42	-42
Greece	33	-23	-30	-30
Hungary	76	17	3	3
Ireland	79	-35	-57	-57
Italy	194	0	-18	-25
Latvia	9	29	8	8
Lithuania	26	15	-15	-15
Luxembourg	4	-15	-33	-33
Malta	1	79	88	-16
Netherlands	113	-35	-39	-49
Poland	227	4	-2	-4
Portugal	25	2	-4	-26
Romania	77	7	-4	-4
Slovakia	13	34	2	2
Slovenia	8	-10	-42	-43
Spain	202	-9	-17	-30
Sweden	13	-16	-29	-29
United Kingdom	284	-20	-36	-36

Table 5.13. Nitrous oxide emission in 2000 for EU-27 in kton N_2O-N, according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 and ND full 2020 scenarios and the WFD 2020 scenario. Results for Malta and Cyprus are not included because inconsistency in the data statistics.

Country	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton N	% change compared to ND partial 2000		
EU-27	368	0	-4	-6
Austria	5	-11	-14	-14
Belgium	9	0	-17	-19
Bulgaria	5	-6	0	0
Cyprus	0	29	32	0
Czech. Rep	8	17	19	19
Denmark	9	-1	-8	-8
Estonia	1	15	14	14
Finland	4	-14	-31	-31
France	67	-1	-7	-9
Germany	49	-2	-12	-12
Greece	8	-10	-13	-13
Hungary	8	32	34	34
Ireland	15	-17	-26	-26
Italy	31	7	1	-4
Latvia	1	18	18	18
Lithuania	3	12	16	16
Luxembourg	0	-8	-15	-15
Malta	0	59	69	-5
Netherlands	17	-16	-13	-20
Poland	28	6	6	5
Portugal	4	15	13	0
Romania	12	14	20	20
Slovakia	2	29	31	31
Slovenia	1	-4	-10	-10
Spain	33	4	2	-6
Sweden	5	-3	-5	-5
United Kingdom	40	-6	-9	-9

Table 5.14. Methane emission in 2000 for EU-27 in kton CH_4, according to the ND partial 2000 scenario, and the calculated potential changes relative to 2000 for the ND partial 2010 and ND full 2020 scenarios and the WFD 2020 scenario.

Country	ND partial 2000	ND partial 2010	ND full 2020	WFD 2020
	kton CH4	% change compared to ND partial 2000		
EU-27	9848	-8	-10	-10
Austria	181	-9	-10	-10
Belgium	249	-4	-9	-9
Bulgaria	89	-14	-14	-14
Cyprus	13	1	1	1
Czech. Rep	142	-7	-7	-7
Denmark	237	-3	-8	-8
Estonia	22	-1	-5	-5
Finland	90	-14	-36	-36
France	1558	-6	-6	-6
Germany	1372	-11	-17	-17
Greece	201	-2	-2	-2
Hungary	101	-5	8	8
Ireland	550	-17	-25	-25
Italy	986	-4	-7	-7
Latvia	30	0	-3	-3
Lithuania	81	-8	-10	-10
Luxembourg	13	-7	-15	-15
Malta	2	2	2	2
Netherlands	479	-12	-6	-6
Poland	517	-7	-10	-10
Portugal	176	9	3	3
Romania	339	-4	-4	-4
Slovakia	61	5	5	5
Slovenia	41	5	6	6
Spain	1028	-1	0	0
Sweden	142	-6	-6	-6
United Kingdom	1146	-23	-23	-23

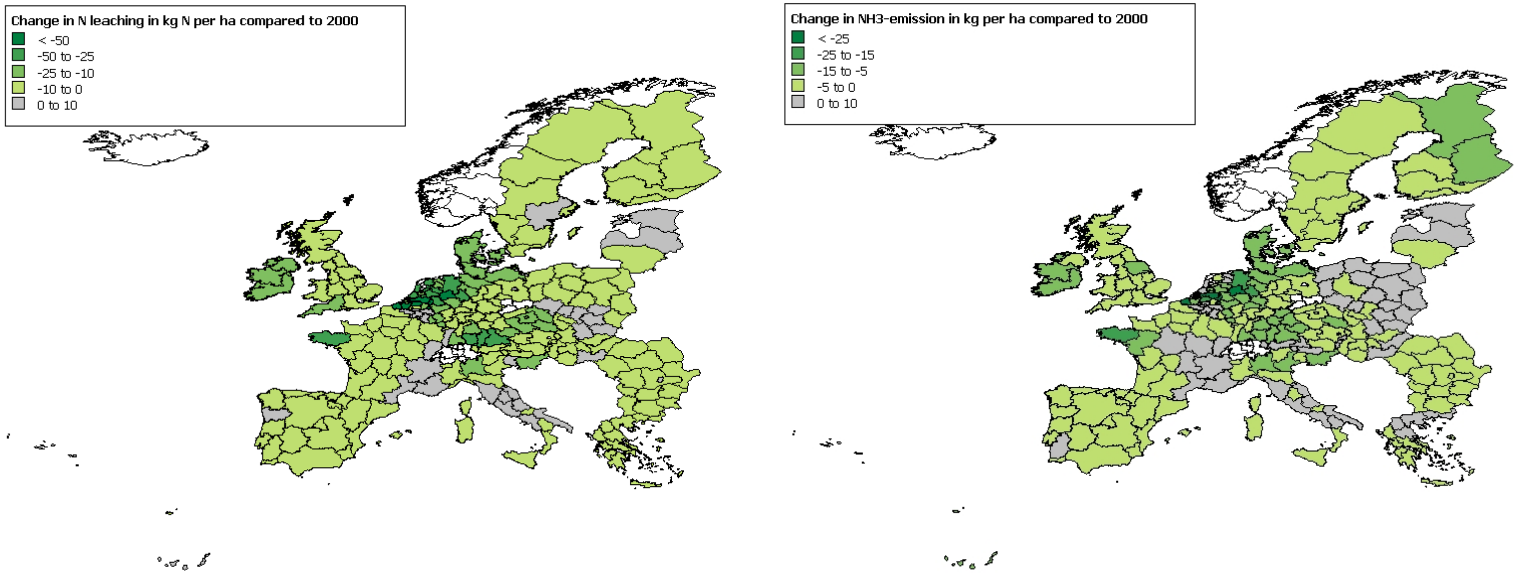


Figure 5.9. Change in N leaching (left map) and NH_3 emission (right map) in kg N per ha agricultural after full and strict implementation of the Nitrates Directive compared to the reference year 2000.

6 Uncertainties

MITERRA-EUROPE is derived from existing models (RAINS and CAPRI) and data bases (Eurostat and FAO), supplemented with a new method to calculate N transformations and loss pathways (denitrification, N uptake by the crop, N leaching to groundwater, surface water, runoff) and effects of measures on these loss pathways. Moreover, a new method for the distribution of N fertilizer and manure over crops has been developed. A large number of data sources have been used and combined, and various assumptions had to be made.

Crop yield, area and number of animals are derived from data bases as Eurostat and FAO. The major uncertainties here are the areas and the yields of grassland. Different types of grassland use can be considered (intensively managed, extensively managed, rough grazing, natural). These types of grassland strongly differ in N input (fertilizer and manure) and yield. The treatise of these grasslands in the databases affects the mean estimated emissions per surface area (emissions per ha or per km^2). For example, considering rough grazing (very extensively managed grassland) as agricultural land, will 'dilute' the N emission expressed per ha agricultural land. This is especially the case for countries with a large area of rough grazing. A considerable amount of time was invested to arrive at reasonable estimates of the areas of grassland.

Crop yield and N content of the crop determine the N off take via harvested products and thereby also the N surplus. It is well-known that the N content is dependent on the input of N, but this is mostly not included in models that calculate N balances at country level. In MITERRA-EUROPE a new approach has been included to account for the effect of N input on the N content, but there is clear scope for improvement of this approach. These data also affect the 'balanced N fertilization' concept. The 'balanced N' concepts in MITERRA-EUROPE are based on a straightforward interpretation of the definition of 'balanced fertilization, i.e.,

Σ (input of available N from all sources) = Σ (N output via harvested crop + crop residues)*efficiency factor..

This concept was applied to all Member States equally. The amount of 'available N' was derived from the total N inputs of all sources and their availability fractions, while corrections were made for 'unavoidable N losses'.

The calculation of emissions of NH_3, N_2O, NO_X, and CH_4 and the effects of NH_3 emission abatement measures on these emissions are derived from the RAINS/GAINS model. Data about number of animals and N excretion are also derived from RAINS/GAINS. These data are mainly derived from consultation of experts from member states. This approach has the risk of introducing 'personal bias' and also inconsistency in approaches and data between Member States. Another point for discussion is the calculation of NH_3 emissions as function of total N excretion, while there is increasing empirical evidence that the NH_3 emission is related to the ammonium content ("TAN") and the pH of in the manure. Further, low protein animal feeding and changing the ratio of easy-degradable carbohydrates to the crude protein content of the animal feed affects the total N excretion but also the TAN content and the pH of the animal manure. As a consequence, we believe that the effects of low protein animal feeding on NH_3 emissions may be underestimated by MITERRA-EUROPE.

The leaching module of MITERRA-EUROPE is developed on the basis of desk studies, data bases and expert knowledge. Data about soil properties, climate and crop were derived from the CAPRI Dynaspat project. All main mechanisms that affect leaching (N surplus, crop types, rainfall, soil types, slope) are included in the model. Leaching fractions have been derived at HSMU level, but are up-scaled and presented at NUTS II level only, because the N input via fertilizer and manure is derived at NUTS-2 level. The model considers only the processes on the soil surface and in the top soil. As a consequence, the calculated leaching losses may not represent the N concentrations in surface waters and groundwater.

The implementation of the nitrate leaching abatement measures was derived from information of Action Programmes of EU-15 Member States as summarized by Zwart et al. (2006). The measures and implementation of measures in countries had to be 'translated' to input for MITERRA-EUROPE, by which simplification had to be made. However, it is uncertain how measures are really implemented in practice. This suggests that consultation with experts from the various Member States is needed to verify the assumptions made in MITERRA-EUROPE.

Various preliminary assessments were made of sensitivities and uncertainties in MITERRA-EUROPE that relate to assumptions and data sources. The main factors have been identified. However, further sensitivity and uncertainty analyses are needed, using e.g., Monte Carlo simulations. This would allow identifying the most sensitive factors more precise and thereby would allow focusing further improvements of the model on these factors and assumptions.

Concluding, MITERRA-EUROPE is new integrated N model, developed in a short time, by which many assumptions had to be made. Clearly, there are many uncertainties in the model which affect the results. However, there is also clear scope to improve MITERRA-EUROPE and decrease the uncertainties, which was not possibly in the relative short time of the Service Contract. Below some recommendations for improvements are presented.

Some recommendations for improvements and further studies are:

- To make a quantitative assessments of the uncertainties in this project, e.g. using Monte Carlo simulations. From this assessment, the major uncertainties of the model can be derived and this information can be used to improve the model can be on these factors and assumptions.
- Test the model with results of measurements or result of other models (e.g. the leaching part).

- Assessment of the area of grassland types (intensively managed, extensively managed, natural) and their yields and N contents on a country-basis, because this area significantly affects the results on hectare-basis and is probably not well described in statistical data-bases.
- It is well-known that the N content of crops is related to the N input. It is recommended to obtain country and crop specific N contents and crop residues in order to improve the calculation of N surplus and N demand. Moreover, it is recommended to include in MITERRA-EUROPE a relation between plant-available N and crop yield, so that yields may change if N input changes.
- To derive activity data and emission factors for NUTS 2 regions in order to improve results on region level.

7 Conclusions

With MITERRA-EUROPE, possible synergistic and antagonistic effects of the measures of the UNECE Working Group on Ammonia Abatement Technologies and of the Nitrates Directive and Water Framework Directive can be assessed in an integrated manner. Further, changes in the emissions of NH_3, N_2O, NO_x, and CH_4 to the atmosphere, and leaching of N to groundwater and surface waters, and on the P balance can be assessed on the EU-27 level, country level, and regional level (both NUTS-2 and Nitrate Vulnerable Zones). The effects of policies and measures can be quantitatively assessed and both ancillary benefits and trade offs of policies and measures can be identified. Hence, MITERRA-EUROPE can be used to fine-tune policy instruments and measures aimed at decreasing the emissions of N species from agriculture.

The results of the scenario analyses lead to the following conclusions:

- The NH_3 emission abatement measures of the UNECE Working Group on Ammonia Abatement Technologies are effective in decreasing NH_3 emission but some of these measures increase the emissions of N_2O and the leaching of N. The measures 'low-protein animal feeding' and 'N management' have the potential of inducing synergistic effects, i.e., decreasing all N losses simultaneously. When the NH_3 emission abatement measures are implemented as integrated package and emphasis is given to 'overall N management', the possible antagonistic effects may disappear.
- The nitrate leaching abatement measures of the Nitrates Directive are effective in decreasing N leaching, but some have the potential to increase the emissions of NH_3 according literature. Assessments made by MITERRA-EUROPE indicate indeed that the measures of the Nitrates Directive are effective in decreasing N leaching and that the antagonistic effects are relatively small. Overall, the nitrate leaching abatement measures of the Nitrates Directive (especially balanced fertilization) have the potential of creating synergistic effects.
- The RAINS A 2020 scenario leads to a ~10 % decrease in NH_3 emission in EU-27 by 2020 relative to the reference year 2000, mainly due to a lower N fertilizer use and a less N excretion (due to less domestic animals). The leaching of N to groundwater and surface waters decreases by 9 %. Differences between countries are large.
- The RAINS optimized 2020 scenario lead to a ~21 % decrease in NH_3 emission in EU-27 by 2020 relative to the reference year 2000, mainly due to the implementation of 'cost-effective' NH_3 emission abatement measures. This decrease is less than the decrease (-29%) calculated by RAINS for the same scenario (see Aman et al., 2006). The leaching of N to groundwater and surface waters decreases by 10%.
- The Nitrates Directive scenarios, especially full implementation of the Nitrates Directive and the WFD scenario, have a strong effect on the N input via N fertilizer and animal manure, and hence on total N losses. The ND full 2020 and

the WFD 2020 scenarios lead to a ~29 and 31 % decrease in N leaching in EU-27 by 2020 relative to the reference year 2000, respectively. The NH_3 emission decrease by 14 and 17% in the ND full 2020 and the WFD 2020 scenarios, respectively.

- Though effective in decreasing N leaching and gaseous N (NH_3, N_2O and NO_X) emission, the ND full 2020 and the WFD 2020 scenarios have significant effects for agriculture. Strict implementation of the code of Good Agricultural Practice and balanced N fertilization according to the Nitrates Directive, and 'equilibrium P fertilization' (in the WFD scenario) will strongly decrease 'the room for N and P fertilizer use and application of animal manure N and P' in various regions in EU-27. Achieving a strong decrease in the application of animal manure N and P will require a combination of low-protein and low-P animal feeding, as well as manure treatment.
- The ND full 2020 and the WFD 2020 scenarios, as defined here, greatly contribute to achieving the targets of the Thematic Strategy on Air Pollution. As yet, the RAINS optimized 2020 scenario did not include the effects of the ND full 2020 and WFD 2020 scenarios. This suggests that new optimizations runs may be needed, taking the measures of the Nitrates Directive and the Water Framework Directive into account, to be able to calculate the most cost-effective combination of measures. Note that the additional costs of the RAINS optimized 2020 scenario relative to the RAINS 2020 scenario have been estimated at €1.6 billion per year for agriculture, equivalent to 2.6 million euro per kton NH_3 per year (Amann et al., 2006).
- Denitrification, with emission of N_2 is the largest N loss pathway in European agriculture, followed by NH_3 volatilization, and N leaching. Emissions of N_2O and NO_X contribute little to the total N loss (but have a significant environmental effect).
- At the suggestions of the reviewers and the Commission, new feedbacks were incorporated in MITERRA-EUROPE (coupling N deposition - NH_3 emissions; coupling crop yield – N input; coupling N uptake by the crop – N input). These feedbacks have made the model more robust but also more complex. Because of these feedbacks, the antagonistic effects of some NH_3 emission abatement measures and of some N leaching abatement measures reported here are smaller compared to the effects reported in the draft final report (21 January 2007 version).

The focus in this service contract was on the development and application of the integrated N model MITERRA-EUROPE. The ammonia results were compared with those of the RAINS model and the other emissions were roughly compared with results of literature. On basis of expert knowledge is was concluded that results were plausible, but it is recommended to carry out an in-depth analyses of the results on both national and NUTS 2 level, using data from literature (e.g. the reports for the Nitrate Directive). In MITERRA-EUROPE many assumptions had to be made. Validations and verification of the assumptions and results are needed. Moreover, it is not clear what the critical assumptions are and how robust the results are. Exploration of the model sensitivity is therefore necessary.

The results of the assessments in task 1 lead to the following recommendations:

- The discrepancy between the results of RAINS and MITERRA-EUROPE in the assessment of the effects of the RAINS optimized 2020 scenario demands further study.
- The strong effects of the ND full 2020 and WFD 2020 on N leaching, gaseous N emissions and on crop yield and N off take demand further study.
- Quantitative sensitivity analyses are needed to assess the effects of major uncertainties in the input and assumptions of MITERRA-EUROPE.

Literature

Amann, M., W. Asman, I. Bertok, J. Cofala, C. Heyes, Z. Klimont, M. Posch, W. Schöpp & F. Wagner. 2006. Emission control scenarios that meet the environmental objectives of the Thematic Strategy on Air Pollution. NEC Scenario Analysis Report Nr. 2. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, 115 pp.

Barton, L., C.D.A. McLay, L.A. Schipper & C.T. Smith, 1999. Annual denitrification rates in agricultural and forest soils: a review. Australian Journal of Soil Research. 37: p. 1073-1093.

Boumans, L.J.M., C.R. Meinardi & G.J.W. Krajenbrink, 1989. Nitraatgehalten en kwaliteit van het grondwater onder grasland in de zandgebieden. Rapport 728472013, RIVM, Bilthoven, 43 pp.

Breeuwsma, A., J.P. Chardon, J.F. Kracht & W. de Vries, 1991. Pedotransfer functions for denitrification. In: Soil and groundwater research report II: 'Nitrate in soils'. Directorate General Science, Research and Development, EUR 13501, 207-217.

Chambers, B. & O. Oenema (2004) Pollution problems: Mitigation or we swapping one form of pollution for another. Pp 606-608. In: D.J. Hatch, D.R. Chadwick, S.C. Jarvis and J.A. Roker (eds.) Controlling N Flows and Losses. Wageningen Academic Publishers. Wageningen, The Netherlands, 624 pp

Culley, J.L.B. & P.A. Phillips, (1989) Retention and loss of N and solids from unlined earthen manure storages. Transactions-of-the-ASAE. 32: 677-683.

De Sutter, T.M., G.M. Pierzynski & J.M. Ham (2005) Movement of lagoon-liquor constituents below four animal-waste lagoons. Journal of Environmental Quality 34, 1234-1242.

De Vries W, J. Kros, O. Oenema & J. de Klein (2002) Uncertainties in the fate of N II: A quantitative assessment of the uncertainties in major N fluxes in the Netherlands. Nutrient Cycling in Agroecosystems 66, 71 – 102.

Dewes, T. (1995) N losses from manure heaps. P. 309-317In: Kristensen et al. (eds.) N leaching in ecological agriculture. Proceedings of an International Workshop, Royal Veterinary and Agricultural University, Copenhagen, Denmark.; AB Academic Publishers,. Bicester, UK.

EEA, 2003. Europe's Environment: The Third Assessment, Environmental Assessment Report No.10, Copenhagen, Denmark.

Eghball,B, J.F. Power, J.E. Gilley & J.W. Doran (1997) Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. Journal of Environmental Quality 26,: 189-193.

Freibauer, A. (2003) Regionalised inventory of biogenic greenhouse gas emissions from European agriculture. European Journal of Agronomy 19, 135-160.

Galloway J.N., J.D. Aber, J.W. Erisman, S.P. Seitzinger, R.W. Howarth, E.B. Cowling & B.J. Cosby 2003. The N Cascade, BioScience 53: 341-356.

Galloway, J.N., E.B. Cowling, S.P. Seizinger & R.H. Socolow 2002. Reactive N; Too much of a good thing?. Ambio 31: 60-71.

Gooddy, D.C. (2002) Movement of leachate from beneath turkey litter sited over chalk in Southern England. Journal of Environmental Science and Health Part B. Pesticides, Food Contaminants, and Agricultural Wastes. 2002; 37(1): 81-91

Gooddy, D.C., P.J.A. Withers, H.G. McDonald & P.J. Chilton, (1998) Behaviour and impact of cow slurry beneath a storage lagoon: II. Chemical composition of chalk porewater after 18 years. Water, Air, Soil Pollut, 107: 51–72.

Ham, J.M. & T.M. DeSutte (1999) Seepage losses and N export from swine-waste lagoons: a water balance study. Journal of Environmental Quality. 28: 1090-1099

Hassink, J. 1995. Organic matter dynamics and N mineralization in grassland soils. Proefschrift Landbouwuniversiteit Wageningen, 250 p.

Heathwaite A.L. 1990. The effect of drainge on nutrient release from fen peat and its implications for surface water quality – a laboratory simulation. Water, Air and Soil Pollution 49: 159-173.

Klimont, Z. & C. Brink, 2004, Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. IIASA IR 04-048.

Korsaeth, A. & R. Eltun, (2000): N mass balances in conventional, integrated and ecological cropping systems and the relationship between balance calculations and N runoff in an 8-year field experiment in Norway, Agriculture, Ecosystem & Environment Volume 79, 199-214

Koops, J.G., O. Oenema & M.L. van Beusichem (1996) Denitrification in the top and sub soil of grassland on peat soils. Plant and Soil 184, 1-10.

Kristensen, H.L. & K. Thorup-Kristensen, 2004. Root growth and nitrate uptake of three different catch crops in deep soil layers. Soil Science Society of America Journal, 68, 529-537

Kuczybski, T., U. Dammgen, J. Webb & A. Myczko (Eds.) 2005 Emissions from European agriculture. Wageningen Academic Publishers, 384 pp.

Lord E.I., S.G. Anthony & G. Goodlass (2002) Agricultural N balance and water quality in the UK. Soil Use and Management 18, 363-369.

Menzi, H. (2002) Manure management in Europe: results of a recent survey. In Proceedings of the 10th International Conference of the RAMIRAN network, May 2002 in Strbske Pleso, high Tatras, Slovak Republic..

Monteny, G.J., C.M. Groenestein & M.A. Hilhorst, 2001. Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. Nutrient Cycling in Agroecosystems 60: 123-132.

Oenema O. & S. Tamminga (2005) N management in animal production systems. Science in China.

Peeters, A. & S. Kopec, 1996. Production and productivity of cutting grassland in temperate climates of Europe. Grassland science in Europe 1. pp 59-73.

Schothorst, C.J. 1977. Subsidence of low moor peat soils in the western Netherlands. Geoderma 17: 265-291.

Sommer S.G. (2001) Effect of composting on nutrient loss and N availability of cattle deep litter. European Journal of Agronomy. 2001 14: 123-133.

Sommer, S.G. & P. Dahl, (1999) Nutrient and carbon balance during the composting of deep litter. Journal of Agricultural Engineering Research 74: 145-153.

Schröder, J.J., H.F.M. Aarts, J.C. van Middelkoop, M.H.A. de Haan, R.L.M. Schils, G.L. Velthof, B. Fraters & W.J. Willems, 2005. Limits to the use of manure and mineral fertilizer in grass and silage maize production, with special reference to

the EU Nitrates Directive. Report 93, Plant Research International, Wageningen, 48 pp.
Schröder J.J., H.F.M. Aarts, J.C. van Middelkoop, G.L. Velthof, B. Fraters & W.J. Willems (2006) Limits to the use of manure and mineral fertilizer in grass and silage maize production on sandy soils in The Netherlands. Accepted for publication in European Journal of Agronomy.
Sheldrick W, J.K. Syers & J. Lingard (2003) Contribution of livestock excreta to nutrient balances. Nutrient Cycling in Agroecosystems 66: 119–131, 2003. 119
Steenvoorden, J.H.A.M., 1988. Vermindering van stikstofverliezen naar grond- en oppervlaktewater. Nota 1849, ICW, Wageningen, 27 pp.
Tiktak, A., J.J.T.I. Boesten, A.M.A. van der Linden & M. Vanclooster (2006) Mapping Ground Water Vulnerability to Pesticide Leaching with a Process-Based Metamodel of EuroPEARL. Journal of. Environmental. Quality 35, 1213–1226.
Van Beek C.L., E.W.J. Hummelink, G.L. Velthof & O. Oenema (2003) N losses through denitrification from an intensively managed grassland on peat soil. Biology and Fertility of Soils 39(4), in press.
Van der Meer, H.G., 1991. Stikstofbenutting en -verliezen van gras- en maïsland. Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij. Rapport nr. 10. DLO, Wageningen. 134 pp.
Van Egmond, K., T. Bresser & L. Bouwman, 2002. The European N case. Ambio 31: 72-78.
Van der Veeren, R.J.H.M. 2002. Economic Analyses of Nutrient Abatement Policies in the Rhine Basin. PhD thesis Free University of Amsterdam, 272 pp.
Velthof, G.L., O. Oenema & P.J. Kuikman (2002) MITERRA-DSS: a decision support system to optimize the mitigation of greenhouse gases from agriculture. In: J. van Ham, A.P.M. Baede, R. Guicherit & J.G.F.M. Williams-Jacobse (eds.) Non-CO_2 greenhouse gases: scientific understanding, control options and policy aspects. Millpress Science Publishers, Rotterdam, pp. 505 – 506.
Velthof, G.L. & P.J. Kuikman (2000) Beperking van lachgasemissie uit gewasresten. Een systeemanalyse. Alterra-rapport 114-3, 81 pp. In Dutch.
Vogt, J.V. et al. (2003). CCM River and Catchment Database for Europe, Version 1.0. EC-JRC, EUR 20756 EN.
Wachendorf, M., M. Büchter, H. Trott & F. Taube, 2004. Performance and environmental effects of forage production on sandy soils. II. Impact of defoliation system and N input on nitrate leaching losses. Grass and Forage Science 59, 56-68.
Withers, P.J. A., H.G. McDonald, K.A. Smith & C.G. Chumbley, Behaviour and impact of cow slurry beneath a storage lagoon (1998): I. Groundwater contamination 1975–1982. Water, Air, Soil Pollution, 107: 35–49.

Appendix 1 Leaching fractions and area Nitrate Vulnerable Zones

Average leaching fraction and area of Nitrate Vulnerable Zones (NVZ). For the NVZ, the current situation and the expected situation in 2020 are presented. The predictions are made by Joint Research Centre.

Country	Leaching fraction				Area NVZ, % of agricultural land	
	runoff	groundwater	surface water*	denitrification	Current	Expected for 2020
	% of applied N**	% of corrected N surplus***				
Austria	3	9	0	91	100	100
Bulgaria	11	25	1	74	0	0
Belgium	5	31	2	67	30	61
Cyprus	3	14	0	86	0	0
Czech. Rep	9	31	1	68	38	38
Germany	4	20	1	79	100	100
Denmark	3	29	1	70	100	100
Estonia	5	23	4	73	0	7
Greece	2	8	0	92	12	19
Spain	3	14	0	85	13	21
Finland	1	3	2	96	100	100
France	3	18	1	82	51	53
Hungaria	5	17	3	81	45	45
Italy	4	17	1	82	11	26
Lithuania	8	35	4	62	100	100
Luxembourg	7	26	3	71	100	100
Latvia	5	24	4	72	13	13
Malta	3	14	0	86	0	0
Netherlands	3	26	4	70	100	100
Poland	5	19	2	79	2	2
Portugal	3	12	0	88	5	10
Romania	8	24	1	75	0	0
Sweden	1	5	1	94	49	49
Slovenia	3	13	1	86	100	100
Slovakia	5	22	1	77	38	38
United Kingdom	3	24	2	75	40	81

* large surface water, i.e. surface present on CCM River and Catchment data base (Vogt et al., 2003)

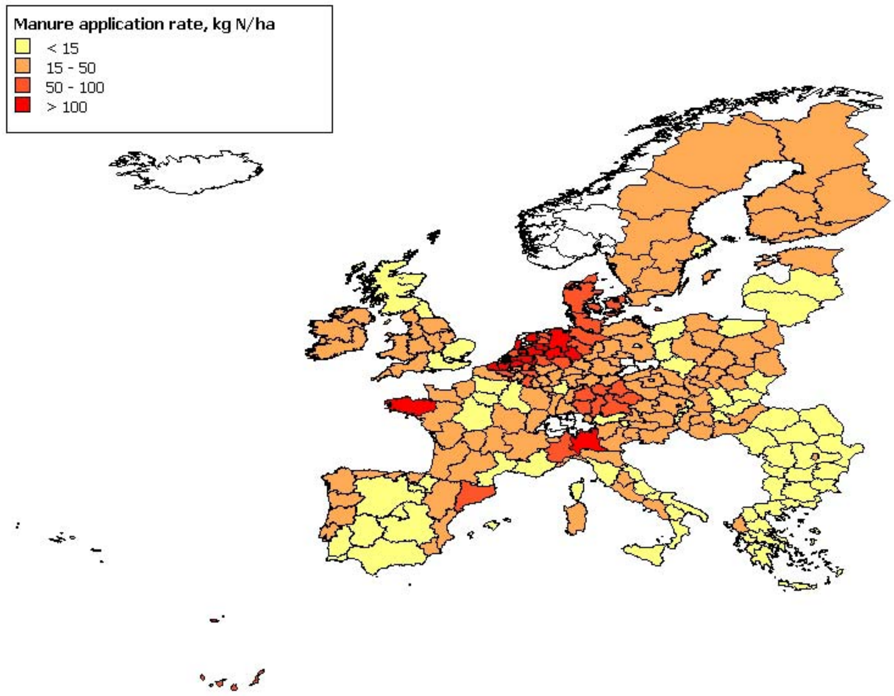
** N applied as fertilizer and manure, and N excreted during grazing

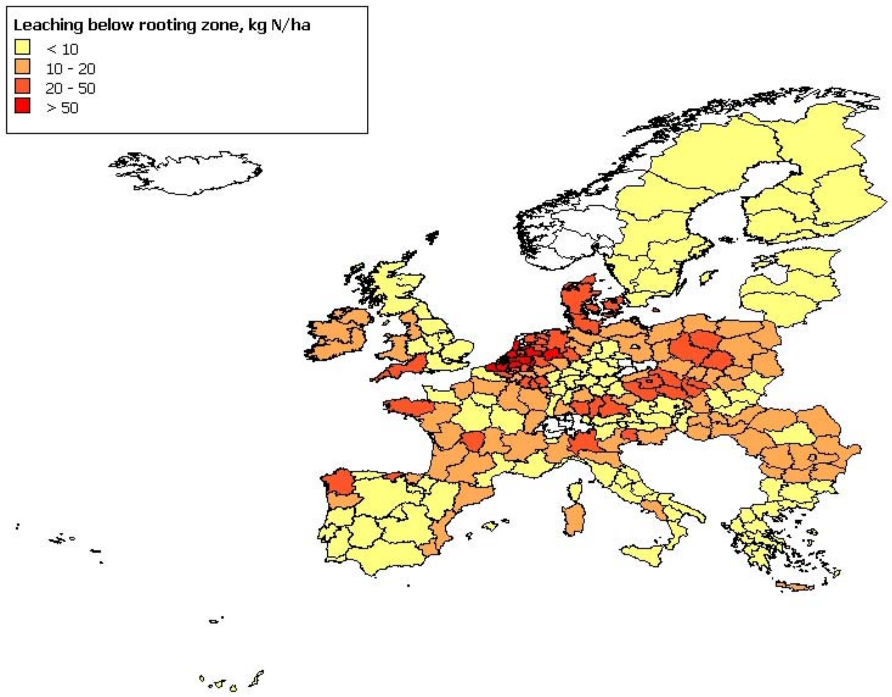
*** N surplus on soil balance corrected for NH3 losses, and surface runoff

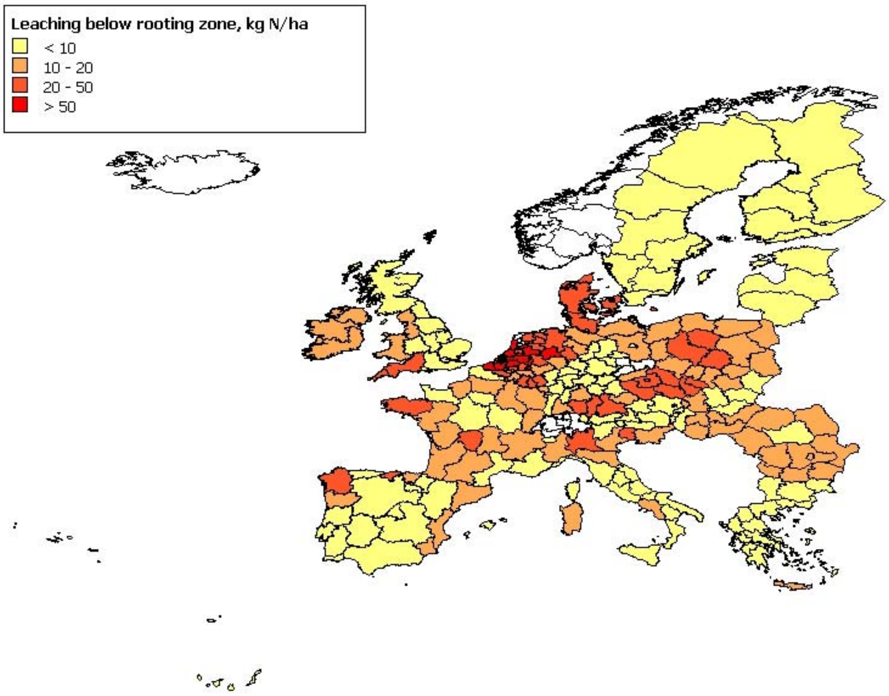
Appendix 2 Comparison of RAINS and MITERRA-EUROPE for 2000

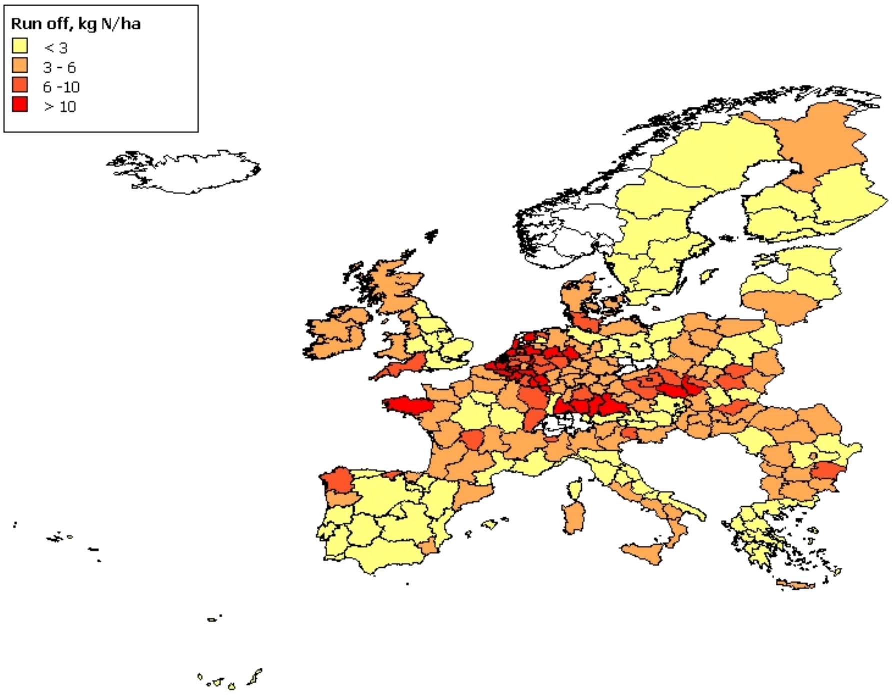
Country	mineral N fertilizer use, kton/year		NH3 emission, kton/year			
	RAINS	MITERRA	mineral fertilizer		housings, storage, soil	
			RAINS	MITERRA	RAINS	MITERRA
AT	121	118	4	3	51	48
BL	145	145	3	3	74	74
BG	145	145	7	7	32	31
CY	8	8	0	0	5	5
CZ	213	263	12	15	67	63
DK	252	234	7	6	78	77
ES	125	114	112	101	234	237
EE	22	22	1	1	8	7
FI	167	167	2	2	30	29
FR	2571	2316	150	135	515	486
DE	1848	1848	81	82	470	453
GR	285	285	14	14	36	34
HU	320	320	16	15	58	55
IR	408	368	23	21	99	97
IT	786	828	80	84	309	293
LV	29	28	2	2	10	9
LT	98	98	8	8	23	22
LU	*	*	*	*	4	3
MT	0	0	0	0	1	1
NL	339	300	10	9	126	124
PL	896	896	77	77	215	202
PT	170	113	11	7	50	47
RO	*	239		20	123	116
SK	82	82	4	4	24	23
SI	34	35	2	2	18	17
SE	189	197	2	2	44	42
UK	1036	1115	33	35	253	252

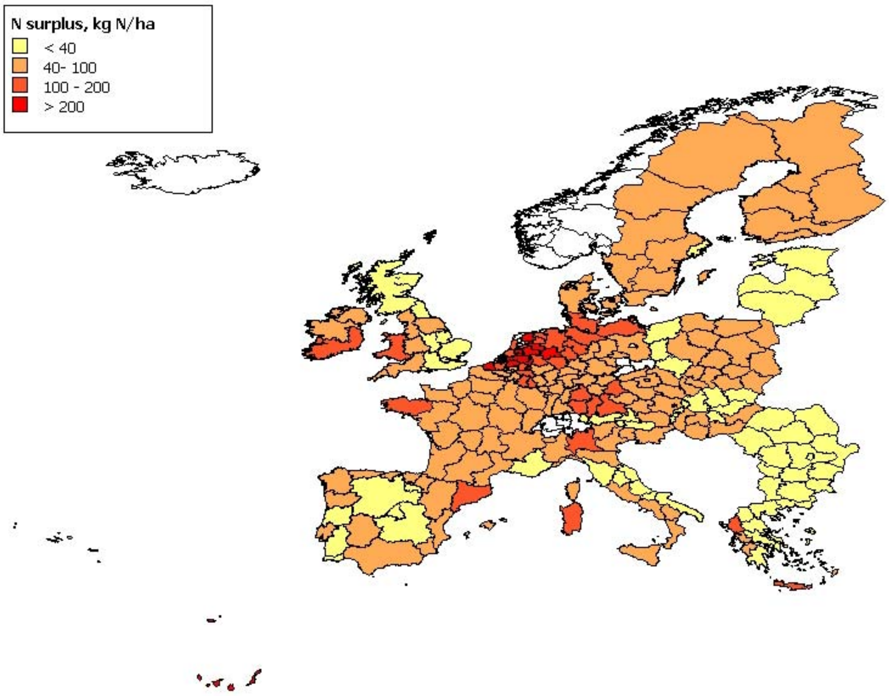
Appendix 3 Maps on NUTS 2 level for 2000.

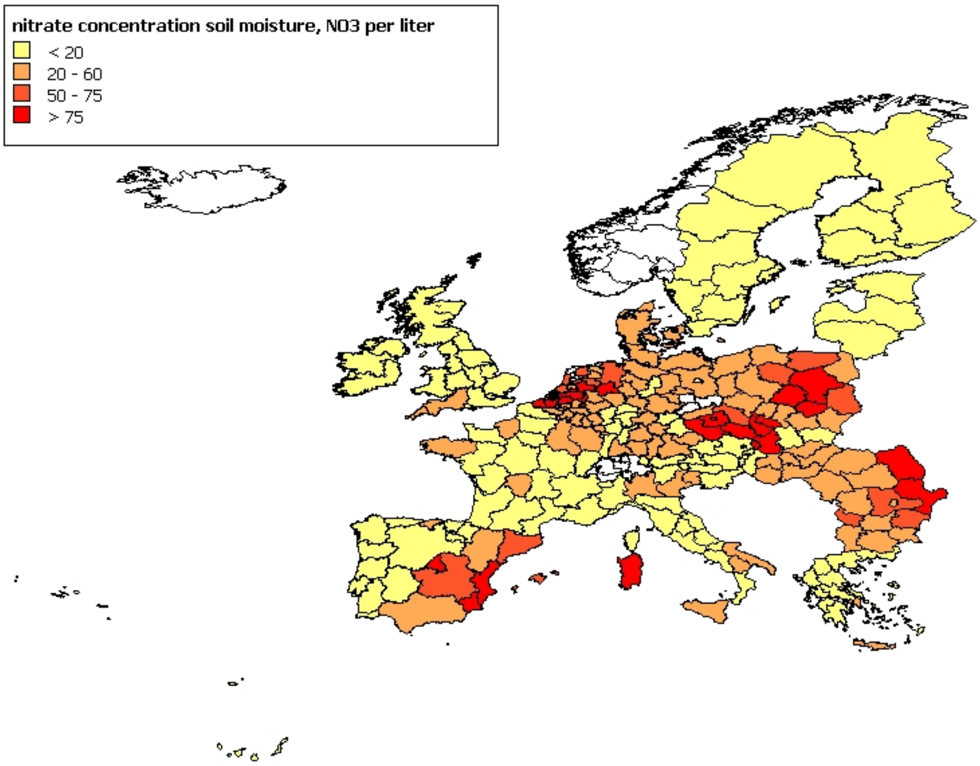


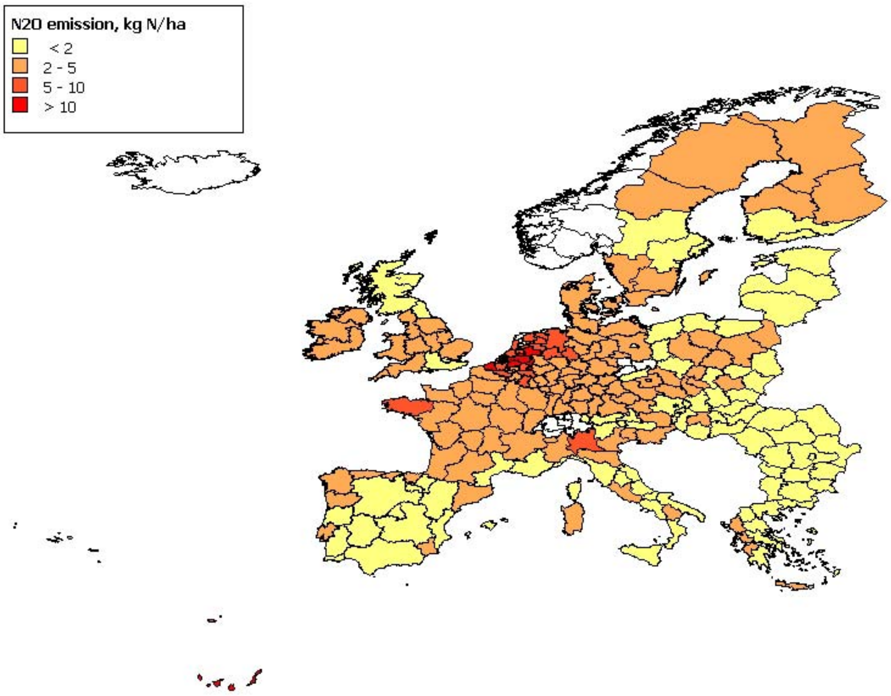



Leaching below rooting zone, kg N/ha
< 10
10 - 20
20 - 50
> 50


Run off, kg N/ha
< 3
3 - 6
6 -10
> 10


N surplus, kg N/ha
< 40
40- 100
100 - 200
> 200


nitrate concentration soil moisture, NO3 per liter
< 20
20 - 60
50 - 75
> 75


N2O emission, kg N/ha
< 2
2 - 5
5 - 10
> 10

Appendix 4 Change in fertilizer and manure application in NVZ and non-NVZ after implementation of the Nitrates Directive.

Change in fertilizer application and manure application in Nitrate Vulnerable Zones (NVZ) and non-NVZ after full implementation of the Nitrates Directive in 2020 (ND full 2020 in table 4.1), compared with the reference year 2000 (RAINS A 2000 in table 4.1).

	fertilizer application, change in %		manure application, change in %	
	non-NVZ	NVZ	non-NVZ	NVZ
Austria		-35		1
Belgium	-11	-20	-35	-35
Bulgaria	4		-7	
Cyprus	-5		18	
Czech. Rep	6	-4	11	11
Denmark		-41		-5
Estonia	-2		21	
Finland		-41		-27
France	-10	-32	-29	-28
Germany		-30		-18
Greece	-30	-54	-15	-38
Hungary	22	-14	37	37
Ireland		-30		-23
Italy	-4	-29	-2	-4
Latvia	24	20	18	22
Lithuania		17		17
Luxembourg		-25		-7
Malta	144		91	
Netherlands		-38		-19
Poland	7	-19	6	10
Portugal	-3	-35	6	-28
Romania	6		14	
Slovakia	24	13	22	22
Slovenia		-21		-3
Spain	-25	0	7	51
Sweden	-12	-29	9	4
United Kingdom	2	-24	-11	-10

Appendix 5 Review of task 1

The work in task 1 of the Service Contract No 070501/2005/422822/MAR/C1- "Integrated measures in agriculture to reduce ammonia emissions" was reviewed by a group of scientists and discussed in a meeting at 24 and 25 January, 2006, in Wageningen, the Netherlands.

The reviewers were: Gerhard Zethner (Umwelt Bundesamt), Stefan Pietrzak, (IMUZ), Miriam Pinto (NEIKER), Mark Sutton (CEH), Bill Healy (CEH), Hans van Grinsven (MNP), Jan-Willem Erisman (ECN), Hans Kros (Alterra), and Wim de Vries (Alterra).

The consortium of the Service contract was represented by Peter Witzke (EuroCare), Gerard Velthof (Alterra), Oene Oenema (Alterra) and Gert-Jan Monteny (ASG-Wageningen-UR).

The review procedure was as follows:

Identification of main issues
1. Main highlights, strong points
2. Main biases and limitations
3. Main messages
4. Suggestions for improvement

The different issues were rated:
1. very important; this means for issue "main biases and limitation": try do it now;
2 important but do it in another project

Nr	Main highlights, strong points	score	Status in final version
1	The development of the integrated model MITERRA-EUROPE that provides insights in the current policy questions is a great achievement	1	
2	The results of MITERRA-EUROPE have shown that there is potential for achieving the NH3 emission objectives of the Thematic Strategy	1	
3	The potential of Nitrates Directive to contribute to the objectives of ammonia emissions reductions (especially through the measure balanced fertilization), has been clearly indicated by MITERRA-EUROPE	2	
4	The development of MITERRA leads to a solid basis to further validation and improvement of related models at EU scale (e.g. RAINS, CAPRI), and leads to synergy	2	

Nr	Main biases and limitations	score	
1	The description of the mineralization of soil organic N in MITERRA-EUROPE could be improved	2	Is done
2	MITERRA-EUROPE misses a few feed backs. It may overestimate the pollution swapping of ammonia abatement measures to nitrate leaching and N2O emissions, because (i) because there is no linkage yet between NH3 emission and N deposition, (ii) crop yields are independent of N input. It was also argued that MITERRA-EUROPE in some cases may underestimate pollution swapping effects	1	Is done
3	MITERRA-EUROPE does not account for temporal dynamics in the ecosystem and the consequences of this lack for the results on nitrate leaching and pollution swapping should be addressed in the report (i.e. time lag)	2	
4	Ammonium leaching and organic N leaching is not precisely mentioned in the reports. The emission of organic compounds to the atmosphere is not treated at all	2	Leaching of ammonium and organic N are included.

Nr	Main messages	score	
1	There is a clear lack of consistent data on grassland areas, grass yields and N content, and the animal number relying on these grasslands, as well the management of the manure and fertilizers, housing systems in official data statistics.	1	
2	There is a threat of pollution swapping through implementation of some policy instruments, and the tool MITERRA-EUROPE can show and quantify this pollution swapping between pollutants	1	

Nr	Suggestions for improvement	score	
1	Further comparison of N surpluses calculated by MITERRA those of OECD and literature data is needed	1	Is done.
2	Explaining the balanced fertilization module in MITERRA relative to current fertilization practices and fertilizer recommendations is needed	2	
3	More presentation of results of member states needed;	2	Is done.
4	In an additional project, the input data of the various Member States should be used discussed with representatives of these Member States, so as to improve the input data of the model as well as the model itself	2	
5	More results should be presented to show how pollution	1/2	Is done.

	swapping can be circumvented, when the measures are integrated. The results of all pollutants should be presented in a more integrated way, i.e. all emissions to the atmosphere, groundwater and surface waters, including methane. Further estimations of pollution swapping issues would require new scenarios.		
6	Using different data sources (from RAINS, EUROSTAT, FAO, CAPRI, etc.) has the potential disadvantage of creating inconsistencies in the total dataset. There is a need for consistency check.	2	
7.	There is a need for sensitivity and uncertainty analyses, especially for the grassland part. However, extensive testing should be done at a later stage	1	Is partly done.
8.	There should be coupling between N emission to the atmosphere and N deposition. This would require including natural areas…. So far MITERRA only calculates for agricultural land….(this was the request by the Commission), but it could be beneficial to include natural land as well	2	
9	The order / sequence of the measures should receive further attention; what is the effect of the order of implementation of the measures on the results and especially on pollution swapping.	1	