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W. de Vries
J. Kros
J.C. Voogd
J. P. Lesschen
D.A. Oudendag
E. Stehfest
A.F. Bouwman


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ABSTRACT

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In this study we compared three relatively simple process based models, developed for the national scale (INITIATOR2), European scale (MITERRA) and global scale (IMAGE), with respect to their response to structural and technological changes in the agricultural systems based on the IPCC B2 baseline scenario for the period 2000– 2030. Changes are predicted by the IMAGE model and relate to crop yield, crop area, animal numbers and N fertilizer inputs. The predicted relative changes by IMAGE are used in INITIATOR2 and MITERRA while relating the animal categories and crop categories in IMAGE to those in the latter models. A comparison was made of NH_3 , N_2O, NO_x and CH_4 emissions, while making a distinction between housing systems, grazing and manure/fertilizer application and N leaching to ground water and N runoff to surface water, while making a distinction between grass land and arable land. The objective of the comparison was to get experience in linking the models across scales and to evaluate scale effects, in terms of aggregating input data, and modeling approach on the model outcomes. The results show that on a high spatial resolution (i.e. within a country when comparing INITIATOR2 and MITERRA and between countries when comparing MITERRA and IMAGE results) there are considerable variations between the model results. However, the results of INITIATOR and MITERRA are quite comparable at the national scale and the results of IMAGE and MITERRA compare quite well at the European (EU27) scale. The reasons for the differences in model results are discussed in terms of the differences in the use of basic data (e.g. data on animal numbers and crop yields) and in excretion, emission, uptake and leaching factors. Unlike the national and continental scale predictions, results show that the area exceeding critical N loads and the average level of N exceedance is largely affected by spatial aggregation of the input data. This holds specifically for effects on ground water quality (N leaching) and to a lesser extent for impacts on biodiversity (N deposition).
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Keywords: nitrogen, green house gases, modeling, scaling, ammonia, methane, nitrous oxides, leaching, agriculture

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Phone: + 31 317 480700; fax: +31 317 419000; e-mail: info.alterra@wur.nl

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Contents

Preface

The objective of the BSIK-IC2 project is an "Integrated analysis of emission reduction over regions, sectors, sources and greenhouse gases". To achieve this goal, models at different scales, from the national to the European to the global scale will be further developed and compared. The "Tool development" is a central element in this project. In this report we describe the results of a so-called "fast track study" in which we compare predictions of N and GHG fluxes at a national scale (INITIATOR2) and European scale (MITERRA) for the years 2000 and 2030 with those derived by IMAGE to assess, amongst others, the impact of aggregating input data on the model outcomes scaling. The various approaches and assumptions used to make these predictions and the results obtained are given in the main text. A description of the various models (IMAGE, MITERRA and INITIATOR2) is given in the Annexes 1, 2 and 3, respectively.

Responsible for the various model actions were Lex Bouwman and Elke Stehfest for IMAGE, Diti Oudendag and Jan Peter Lesschen for MITERRA and Jan-Cees Voogd, Hans Kros and Wim de Vries for INITIATOR2.

Summary

Various model approaches have been developed for assessing emissions of different forms of reactive nitrogen for various parts of Europe at various geographic resolutions and for various time periods. The modelling approaches include emission factor approaches, empirical models, simple process based models and detailed ecosystem models. In this study we compared three relatively simple process based models, developed for the national scale (INITIATOR2), European scale (MITERRA) and global scale (IMAGE), with respect to their response to livestock, land use and management changes in the agricultural systems based on the IPCC B2 baseline scenario for the period 2000– 2030. Changes are predicted by the IMAGE model and relate to crop yield, crop area, animal numbers and N fertilizer inputs. The predicted relative changes by IMAGE are used in INITIATOR2 and MITERRA while relating the animal categories and crop categories in IMAGE to those in the latter models.

A comparison was made of the following fluxes: (i) NH_3 , N_2O and NO_x emissions, while making a distinction between housing systems, grazing and manure/fertilizer application, (ii) CH_4 emissions and (iii) N leaching to ground water and N runoff to surface water, while making a distinction between grass land and arable land. We compared predictions for the years 2000 and 2030 for: (i) the Netherlands between INITIATOR2 and MITERRA and (ii) Europe (27 EU countries) between MITERRA and IMAGE. The objective of the comparison was to get experience in linking the models across scales and to evaluate scale effects, in terms of aggregating input data, and modelling approach on the model outcomes.

At the national and continental scale, the comparison is quite good. For the year 2000, the results of INITIATOR and MITERRA at the national scale (the Netherlands) are within 10% for the N inputs (except for N fixation) and within 25% for most of the N outputs (crop uptake, NH_3 and N_2O emissions and N leaching). Larger differences up to 60% occur for NO_x emissions and runoff. Similarly, the results of IMAGE and MITERRA compare quite well at the European scale (all EU 27 countries). Total N inputs compare within 10%, although individual sources such as grazing and deposition deviate up to 30%, and most of the N outputs deviate by less than 30% (crop uptake, NH_3 and N_2O emission). Larger differences up to 100% occur for NO_x emissions and the sum of leaching and runoff.

The comparability of predictions is different in 2030 as compared to 2000, due to differences in model assumptions. For example, an efficiency increase in N use in the period 2000-2030 is assumed in INITIATOR2 but not in MITERRA. Consequently, where the N input by animal manure for the whole of the Netherlands is quite comparable in 2000, it deviates by approximately 20% in 2030. Inversely, the estimated total NH_3, N_2O and NO_x emissions by INITIATOR2 are approximately 20-40% higher than the estimate by MITERRA in the year 2000, but emissions in the

year 2030 are comparable for both models. An efficiency increase in N use in the period 2000-2030 is also assumed in IMAGE and similar effects occur.

Unlike the national and continental scale predictions, results show that the area exceeding critical N loads and the average level of N exceedance is largely affected by spatial aggregation of the input data. In this study, this holds specifically for effects on ground water quality (N leaching leading to NO_3 concentrations exceeding the limit of 50 mg NO_3/l) and to a lesser extent for impacts on terrestrial biodiversity (N deposition levels exceeding critical N loads). In summary, results imply that spatial aggregation have a limited effect on most national and continental scale N inputs and on N emission estimates, except for NO_x but a large effect on the exceedance of critical NO_3 concentrations and to a lesser extent critical N loads. The large uncertainty in exceedance of critical NO_3 concentrations is also reflected by the uncertainty in N leaching and N runoff estimates, both at the national and European scale. Differences in model results are mainly due to differences in the use of basic data such as animal numbers and crop yields and in excretion, emission, uptake and leaching factors, and to a lesser extent related to differences in model structure.

1 Introduction

Background

Various models approaches have been developed for assessing emissions of different forms of reactive nitrogen such as NH_3, N_2O and NO_x emissions and N leaching and N runoff for various parts of Europe at various geographic resolutions and for various time periods. The modelling approaches vary from: (i) emission factor approaches at various spatial resolutions, such as UNFCC/IPCC (IPCC, 2006), EDGAR (Van Aardenne, 2002), GAINS (Höglund-Isaksson & Mechler, 2005; Winiwarter, 2005) and EMEP (Simpson et al., 2003) to (ii) models combining more detailed emission factor approaches with simple process based and empirical models, such as IMAGE (Alcamo, 1994; Leemans et al., 1998; MNP, 2006), MITERRA (Velthof et al., 2009) and INITIATOR (De Vries et al., 2005b) and (iii) detailed ecosystem models, such as DNDC (Li, 2000; Li et al., 2000) and the combination CAPRI-DNDC (Leip et al., 2008).

A crucial question regarding the use of Integrated Assessment Models is which is the most appropriate scale in addressing air quality and water quality impact issues, when moving from global to continental to national and regional scale. With respect to the emission of green house gases, such as N_2O and CH_4, it is crucial to know whether the total emissions for the area considered (e.g. country or continent) is correct. Accurate information on the spatial distribution of the emissions is less relevant, because of strong atmospheric dispersion. The latter aspect is, however, crucial when assessing the risk of elevated NH_3 emissions, and related N deposition, and of N leaching and N runoff in view of eutrophication impacts on terrestrial and aquatic ecosystems. Here, aggregation of input data for large areas may cause accurate average N deposition and N leaching levels, but a strong deviation in the area exceeding critical N deposition loads or critical N concentrations in ground water and surface water. This effect holds for all spatial levels. For this reason, many countries in Europe have developed modelling tools, at national and sub-national scale, having recognized the importance and the need to develop autonomously, integrated assessment analysis on air and water pollution and green house gas emissions, to support the national and local policy makers in developing, scientifically underpinned, cost effective policies for the protection of the environment and the human health.

Aim of the study

In the BSIK-IC2 project entitled "Integrated analysis of emission reduction over regions, sectors, sources and greenhouse gases", models at different scales, going from the national scale model INITIATOR2 (De Vries et al., 2005b) to the European scale model MITERRA (Velthof et al., 2009) and the global scale model IMAGE (Alcamo, 1994; Leemans et al., 1998; MNP, 2006) are further developed. In this report we describe the results of a so-called "fast track study" by comparing predictions of nitrogen and green house gas fluxes for the years 2000 and 2030 for: (i) the Netherlands between the national scale model INITIATOR2 and the

European scale model MITERRA and (ii) Europe (EU-27 countries) between MITERRA and the global scale model IMAGE. A comparison is made of the following fluxes: (i): NH_3 , N_2O and NO_x emissions, while making a distinction between housing systems, grazing and manure and fertilizer application, (ii) CH_4 emissions and (iii) N leaching to ground water and N runoff to surface water, while making a distinction between grass land and arable land. The assessments for the year 2030 by each model are based on IMAGE predictions for base line scenario B2, using the predicted relative changes in animal numbers, land cover/crop shares, crop yields and N fertilizer inputs for this year compared to the year 2000.

The study was carried out to:

- Get experience in linking the models across scales. The scenario variables need to be implemented in a consistent way within the models working on different scales.
- Evaluate scale effects, in terms of aggregating input data, and modelling approach on the model outcomes by comparing results from the national, European and global scale models at an aggregated level and in view of risk assessment with respect to NH_3 emissions and N leaching.
- Identify shortcomings of the current models and define further development

A future aspect in comparing the models is to evaluate mitigation potentials, to (i) identify agreement or contradiction about mitigation potentials as calculated on different scales and (ii) assess whether assumptions on possible emission reduction on a large scale can actually be met according to small scale models, or whether small scale approaches might even show more mitigation potential.

Contents of the report

In chapter 2, the IPCC B2 baseline scenario for the period 2000 – 2030, building on an available scenario from the Eururalis project for IMAGE, is described. This scenario was implemented in all models in the most consistent way possible in which trends for major driving variables from IMAGE are passed to the smaller scales models. A detailed description of the linkage between IMAGE and both MITERRA and INITIATOR2 is provided in chapter 3. Subsequently, the N and GHG fluxes as predicted by the different models are compared in Chapter 4, and differences are discussed. A final discussion and evaluation is presented in Chapter 5. A description of the various models (IMAGE, MITERRA and INITIATOR2) is given in the Annexes 1, 2 and 3, respectively. Actually, for IMAGE, the so-called IMAGE-N version was used. IMAGE-N is, however, denoted as IMAGE in the remainder of this report.

2 The IMAGE baseline scenario

The use of explorative scenarios is a tool that can be useful to gain insight in possible and plausible future fluxes. Scenarios in general start with story lines taking into account the main driving forces towards the future. Using different storylines is one way to take into consideration the potential impact of uncertainties in future foresights. The IMAGE baseline scenario is chosen out of a set of four contrasting scenarios used within Eururalis, based on the general scenario storylines from IPCC related to different world visions, which were made more specific on agricultural policies. In Figure 1 the four scenarios are indicated.

Figure 1 The four Eururalis scenarios as an elaboration of the IPPC SRES scenarios

The baseline used is the regional Communities (B2) scenario with the following characteristics:

- Social and cultural values can best be preserved at the local or regional community level;
- Self-reliance, ecological stewardship and equity are the keys to sustainability;
- No further development of supranational institutions. National governments remain responsible for foreign and security policy, fiscal policy, justice etc.
- CAP subsidies: increase of some 10%, linked to environmental and social targets. Export subsidies are eliminated;
- Import barriers remain in place, to protect local markets against cheap imports;
- Imported goods have to comply with the high EU standards regarding health, environment, and animal welfare;
- No further enlargement of the EU.

The predicted changes in the agricultural systems are changes in animal numbers (production systems), crop area, crop yield and N fertilizer inputs, as described below. The demand, trade and production of crops and animal products is calculated by the GTAP model as described in Annex 1. N excretion rates per animal category are assumed to be constant.

Trends in animal numbers
The demand, trade and production of animal products is provided by the GTAP model. The modules of the animal production systems in IMAGE are used to calculate the number of slaughtered animals the number of animals and their feed requirements from feed crop, grass, fodder etc. A detailed description of the animal production systems is provided in Bouwman et al. (2005a). In this same paper, assumptions on future intensity increase are documented. Mostly they are also based on Bruinsma (2003). As with crops, we assumed for the B2 storyline a slightly lower increase in intensity than estimated by (Bruinsma, 2003)

Trends in crop area and crop yields
The demand, production and trade of agricultural products per region is also calculated by the GTAP model. Allocation of the production on a 30 min grid is done by the Land Cover Change Model (LCM) of IMAGE. Changes in crop area are a result of changes in production and changes in yield. As described in Annex 1, the Terrestrial Vegetation Model (TVM) sub model in IMAGE calculates crop yield on the basis of the potential crop productivity. The fraction of actual yield to potential crop productivity is the so called "management factor" in IMAGE. This management factor is assumed to grow in time, based on (Bruinsma, 2003). Additional to this external trend, yields also change because of the economically driven intensification as calculated by GTAP, through climate change and through change in agricultural area. For the B2 storyline we assumed a slightly lower increase in the management factor than estimated by (Bruinsma, 2003)

Trends in N fertilizer inputs
In IMAGE fertilizer use depends on crop production expressed in dry matter. Hence, with changing crop production, the fertilizer requirement per hectare changes proportionally. However, at the same time the fertilizer use efficiency increases. This is expressed as the dry matter production in kg per kg of N fertilizer. For Western European countries this efficiency is assumed to increase by 20% in the period 2000-2030. The N fertilizer input in Eastern European countries in 2000 is lower than in Western Europe. Therefore IMAGE assumes no change in fertilizer efficiency in Eastern European countries. As a result, N fertilizer use efficiency in Western and Eastern European are about equal in 2030. More details on this approach are given in (Bouwman et al., 2005b).

3 Approach to the linkage of the IMAGE results to MITERRA and INITIATOR2

The spatial resolution of input data used by the models IMAGE, MITERRA and INITIATOR varies in line with the geographic extent of the model. IMAGE uses input data at sub-continental level, but for Europe, an IMAGE version exists that uses agricultural data at country level. MITERRA uses statistical data at the NUTS2 administrative level (NUTS 2; Nomenclature of Territorial Units for Statistics in the EU; ca 230 administrative areas of 160 – 440 km^2). INITIATOR uses data for 4647 so-called STONE plots for agriculture in the Netherlands, that are plots consisting of a multiple of 250m x 250 m grid cells with unique combinations of soil use, soil type (and related soil properties) and ground water table class. Regarding animal numbers, use is made of the so-called CBS/GIAB database containing data for each farm in the Netherlands. The principle of the linkage of the IMAGE results to MITERRA and INITIATOR2 is to superimpose the IMAGE predictions for the period 2000-2030 on animal numbers, crop area, crop yield and N fertilizer use land cover for the various IMAGE animal and crop categories on the more detailed data used by MITERRA and INITIATOR2 in the year 2000. To perform this action, tables are used that allocate the various animal and crop categories in IMAGE to those used by MITERRA and INITIATOR2, as described in detail below.

3.1 Change in animal numbers

In MITERRA, the approach is as follows:

- Use the animal numbers in RAINS/GAINS for the year 2000 (RAINS categories) at country level and the excretion factors for the animal categories in RAINS/GAINS.
- Downscale these numbers to NUTS2 level using the animal categories in CAPRI
- Superimpose the IMAGE predictions for animal numbers in the future in terms of relative changes per country per IMAGE animal category

This requires an allocation of the:

- CAPRI animal categories to those of RAINS/GAINS.
- IMAGE animal categories to those of CAPRI

Information on animal categories used in IMAGE is given in Table 1. The allocations are given in Table 2 and 3. Special features are:

- Asses, Mules, Camels, Buffaloes in IMAGE are downscaled to NUTS2 level based on the area of each NUTS2 region. The excretion factors for horses in RAINS are used to asses the N excretion by MITERRA.
- In MITERRA, horses and fur animals (FURANI) are also included based on RAINS data and downscaled to NUTS2 level based on the area of each NUTS2

region. These animals are included in the calculation, assuming no trends between 2000 and 2030.

Table 1 Animal categories used in IMAGE

IMAGE	FAO database[1]	Product
Dairy cattle	milking cows	milk and beef
Non-dairy cattle	total cattle excluding milking cows, buffaloes	beef
Pigs	pigs	pork
Sheep & goats	Sheep, goats	mutton and goat meat
Poultry	Chickens, ducks, geese, turkeys	poultry and eggs
Other animals	Camels, horses, mules, asses	--

[1] FAO (2007)

Table 2 Allocation of CAPRI animal categories to RAINS animal categories

CAPRI-codes	RAINS-code	RAINS animal category
DCOW	DAICOW	Dairy cows
SCOW, BULL, HEIF, HEIR, CAMF, CAFF, CAMR, CAFR	OCOW	Other cows
PIGF, SOWS	PIGS	Pigs
HENS	LAYHENS	Laying hens
POUF	OPOUL	Other poultry
SHGF, SHGM	SHEGOA	Sheep/Goat
Not available	HORSES, FURANI and ORANI	Horses, Fur animals and Other animals

Table 3 Allocation of IMAGE animal categories to CAPRI animal categories used in MITERRA

IMAGE animal category	CAPRI-code	CAPRI animal category
Dairy cattle	DCOW	Dairy cows
Non-dairy cattle	SCOW, BULL, HEIF, HEIR, CAMF, CAFF, CAMR, CAFR	Other cows
Pigs	PIGF, SOWS	Pigs
Poultry	HENS, POUF	Laying hens, Other poultry
Sheep/Goats	SHGF, SHGM	Sheep/Goat
Asses, Mules, Camels, Buffaloes	Not included[1]	-

[1] Asses, Mules, Camels, Buffaloes are not included in MITERRA but downscaled from IMAGE data. Furthermore, Horses and Fur animals are included in MITERRA from RAINS data

In INITIATOR2, the approach is as follows:

- Use the animal numbers in GIAB/INITIATOR2 for the year 2000 at farm level and the excretion factors for these animal categories in GIAB/INITIATOR2.
- Superimpose the IMAGE predictions for animal numbers in the future in terms of relative changes for the Netherlands per IMAGE animal category for each farm.

This requires an allocation of the GIAB/INITIATOR2 animal categories to those of IMAGE. This allocation is given in Table 4. An example of the trends in animal numbers in terms of ratios between the years 2030 to 2000 is given in Table 5 for the Netherlands. These results are used in INITIATOR2.

For “nertsen, vossen, konijnen, voedsters and vlees- en opfokkonijnen”, not available in IMAGE, we assumed no trend between 2000 and 2030 and the same holds for horses. Note that the data given by IMAGE were in livestock units (lsu).

This followed from a comparison of the ratio of animal numbers in the RAINS/GAINS database for the year 2000 (used in MITERRA) and in IMAGE, using the animal categories in IMAGE at country level. Even though it would be more consistent to use the animal numbers in IMAGE, there was however no problem since we superimposed the IMAGE trends on the MITERRA and INITIATOR2 animal numbers.

Table 4 Allocation of GIAB/INITIATOR2 animal categories to IMAGE animal categories

Code	GIAB/INITIATOR2 animal category (Dutch)	IMAGE animal category
a1	melk/kalfkoeien > 2 jr	Dairy cattle
a2	zoogkoeien en overig rundvee > 2jr	Dairy cattle
a3	vrouwelijk jongvee < 2jr	Dairy cattle
a41	vleeskalveren (rose en witvleesprod)	Non-dairy cattle
a51	vleesstier 0-6 mnd	Non-dairy cattle
a52	vleesstier 6-24 mnd	Non-dairy cattle
b1	schapen > 1 jr	Sheep/Goats
c1	geiten > 1 jr	Sheep/Goats
d11	biggenopfok (gespeende biggen)	Pigs
d12	kraamzeugen (incl. biggen tot spenen)	Pigs
d13	guste en dragende zeugen	Pigs
d2	Dekberen, >=7 mnd	Pigs
d3	Vleesvarkens, opfokberen en –zeugen	Pigs
e1	Opfokhennen en hanen van legras < 18 wk	Poultry
e2	Legkippen	Poultry
e3	Ouderdieren van vleeskuikens in opfok < 19 wk	Poultry
e4	Ouderdieren van vleeskuikens	Poultry
e5	Vleeskuikens	Poultry
f4	Vleeskalkoenen	Poultry
g12	Vleeseenden en ouderdieren van vleeseenden	Poultry
h1	Nertsen	Not available
h2	Vossen	Not available
i1	Konijnen, voedsters	Not available
i2	Vlees- en opfokkonijnen	Not available
j1	Parelhoenders	Poultry
k1	Volwassen paarden	Horses
k2	Paarden in opfok	Horses
k34	Pony's (volwassen en in opfok)	Horses

Table 5 Trends in animal numbers in terms of ratios between the year 2010, 2020 and 2030 as compared to 2000 for the Netherlands (for 2000, ratios are 1.0)

Year	Ratios for animal numbers compared to 2000				
	Dairy cattle	Beef cattle	Sheep/Goats	Pigs	Poultry
2010	0.984	0.832	0.888	0.888	1.045
2020	0.946	0.711	0.807	0.807	1.026
2030	0.907	0.603	0.723	0.723	0.994

3.2 Change in land cover and crop area

In MITERRA, the approach is as follows:
- Use the land cover in CAPRI for the year 2000 (CAPRI crop shares) at NUTS 2 level.
- Superimpose the IMAGE predictions for land cover in the future in terms of relative changes in IMAGE land cover in grassland, arable land and biofuels per country to CAPRI crops at Nuts 2 level.

This requires an allocation of the CAPRI crops to grassland, arable land and biofuels and also to various arable crops used in IMAGE, that is needed when including the change in crop yields and N fertilization. Information on crop categories used in IMAGE is given in Table 6. The allocation procedure used is given in Table 7.

Table 6 Crop categories used in IMAGE in view of crop yields

IMAGE	FAO Crop Suitability Approach[1]	FAO database[2]
Food crops		
Temperate cereals	Wheat (spring) Wheat (winter)	Barley, oats Rye, wheat
Rice	Rice	Rice, paddy
Maize	Maize (temperate) Maize (tropical)	Maize
Tropical cereals	Millet (temperate, tropical) Sorghum (temperate, tropical)	Millets Sorghum
Pulses	Beans (temperate, tropical)	Dry beans, dry peas, chick peas, dry broad beans, green beans, green peas, lentils
Roots & tubers	Cassava, potato	Cassava, potatoes, sweet potatoes, yams
Oil crops	Groundnut, sesame, soya bean, sunflower (temperate, tropical)	Groundnuts, rapeseed, sesame seed, soybeans, sunflower seed
Biofuel crops		
Sugar cane	Sugar cane	-
Maize	Maize	
Woody biomass	Fuel wood species in Adaptability group I, II	
Non-woody biomass	Grass species in Adaptability group III, IV	
Feed crops		
Grass & fodder species	Legume species in Adaptability group I, II Grass species in Adaptability group III, IV Rainfall based pasture productivity	-

[1] See FAO (1978-1981)
[2] See FAO (2007)

In INITIATOR2, the approach is as follows:
- Use the land cover in INITIATOR2 for the year 2000 at STONE plot level.
- Superimpose the IMAGE predictions for land cover in the future in terms of relative changes in IMAGE land cover in grassland, arable land and biofuels for the Netherlands to INITIATOR2 crops at STONE plot level.

This requires an allocation of the INITIATOR2 crops to those of IMAGE. This allocation is given in Table 8, together with an allocation to various arable crops that is needed when including the change in crop yields and N fertilization. For other crops in INITIATOR2, we use the trends in crop yields for all crops in IMAGE. Biofuels are not included in MITERRA and INITIATOR2. We therefore added up the agricultural area and the biofuel area, as biofuels are maize, rapeseed or wheat.

Table 7 Land use classes based on CAPRI used in MITERRA and the allocation to IMAGE crop types used to assess changes in crop shares, crop yields and N fertilizer application rates on arable land

CAPRI LUCAS	CAPRI ID	CAPRI Description	Lumped description in IMAGE		
			Land cover	Crop yields	N fertilizer
Grassland			Grassland	-	Grassland
Arable land			Arable land	-	-
SWHE	1	Common wheat	-	Temperate Cereals	Upland crop
DWHE	2	Durum Wheat	-	Temperate Cereals	Upland crop
BARL	3	Barley	-	Temperate Cereals	Upland crop
RYEM	4	Rye	-	Temperate Cereals	Upland crop
OATS	5	Oats	-	Temperate Cereals	Upland crop
LMAIZ	6	Maize	-	Maize	Maize
PARI	7	Rice	-	Rice	Rice
OCER	8	Other cereals	-	Temperate Cereals	Upland crop
POTA	9	Potatoes	-	Roots& tubers	Upland crop
SUGB	10	Sugar beet	-	Roots& tubers	Upland crop
ROOF	11	Other root crops	-	Roots& tubers	Upland crop
SUNF	12	Sunflower	-	Oil crops	Upland crop
LRAPE	13	Rape and turnip rape	-	Oil crops	Upland crop
SOYA	14	Soya	-	Oil crops	Upland crop
TEXT	15	Fibre and oleaginous crops	-	Temperate Cereals	Upland crop
TOBA	16	Tobacco	-	Temperate Cereals	Upland crop
OIND	17	Other non permanent industrial crops	-	Temperate Cereals	Upland crop
PULS	18	Dry pulses	-	Pulses	Legumes
OFAR	22	Fodder other on arable land; Temporary grasslands	-	Maize	Maize
OCRO	29	Other crops; Permanent industrial crops	-	Oil crops	Upland crop

For INITIATOR2 it is also relevant to get data on the other land categories such that the total area of land remains the same in 2000 and 2030. Major categories missing are remaining non agricultural areas including forests and urban. In the application we assume that the decrease in areas of grassland and arable land is compensated by an increase in nature (1/2) and in urban (1/2). An example of the trends in land cover in terms of ratios between the years 2030 to 2000 is given in Table 9 for the Netherlands.

Table 8 Land use classes used in INITIATOR2 and the allocation to IMAGE crop types used to assess changes in crop shares, crop yields and N fertilizer application rates on arable land

INITIATOR2	Lumped description in IMAGE		
description	Land cover	Crop yields	N fertilizer
Grass land	Grass & fodder species	Grass & fodder species	Grass
Arable land	Arable land	-	-
Arable crops			
Common wheat	-	Cereals	Upland crop
Maize	-	Maize	Upland crop
Other cereals	-	Cereals	Upland crop
Potatoes	-	Root crops	Upland crop
Sugar beet	-	Root crops	Upland crop
Other crops	-	Average of all crops	Upland crop

Table 9 Trends in land cover in terms of ratios between the year 2010, 2020 and 2030 as compared to 2000 for the Netherlands (for 2000, ratios are 1.0)

Year	Ratios agricultural land cover compared to 2000		
	Total	Grass land	Arable land
2010	0.934	0.984	0.888
2020	0.906	0.945	0.865
2030	0.892	0.942	0.842

3.3 Change in crop yields

In MITERRA, the approach is as follows:

- Use the crop yields for the CAPRI crop types for the year 2000 at Nuts 2 level, based on the FAO yields for these crops.
- Superimpose the IMAGE predictions in terms of relative changes in yields for the various IMAGE crop categories (temperate cereals, rice, maize, tropical cereals, pulses, roots & tubers and oil crops) at the level of a region (OECD Europe and Eastern Europe) to CAPRI crops at Nuts 2 level.

This requires an allocation of the CAPRI crops to those of IMAGE, as given already in Table 6.

In INITIATOR2, the approach is similar:

- Use the crop yields for the INITIATOR2 crop types for the year 2000 at STONE plot level, based on the CBS statline data for arable land and expert estimates for grass land at Nuts 2 level.
- Superimpose the IMAGE predictions in terms of relative changes in yields for the various IMAGE crop categories for the Netherlands (temperate cereals, maize, roots & tubers) at the level of OECD Europe to INITIATOR2 crops at STONE plot 2 level.

This requires an allocation of the IMAGE crops to INITIATOR2 crops as given in Table 8. Information on crop yields (in Mg/km^2) is available for the IMAGE crop categories (temperate cereals, rice, maize, tropical cereals, pulses, roots & tubers and oil crops) at the level of a region (OECD Europe and Eastern Europe). As an example, the relative change in crop yield is given in Table 10 for the Netherlands. For grassland we assumed no trends (no information on trends is given in IMAGE).

Table 10 Trends in yield in terms of ratios between the year 2030 as compared to 2000 for the Netherlands (for 2000, ratios are 1.0)

Year	Ratios in crop yield compared to 2000				
	Total	Grass	Cereals	Maize	Roots & tubers
2030	1.0385	1.0	1.0403	0.9693	1.0470

3.4 Change in N fertilizer input

In MITERRA, the approach is as follows:

- Use the calculated N fertilizer rates for the year 2000 at Nuts 2 level, based on MITERRA estimates for N inputs by manure and N requirements by crops and national FAO based N fertilizer data.
- Superimpose the IMAGE predictions in terms of relative changes in N fertilizer data for the various IMAGE crop categories (upland crop, legumes, rice and grass) at the level of a country to CAPRI crops at Nuts 2 level.

This requires an allocation of the CAPRI crops to those used in IMAGE at country level as given already in Table 6.

In INITIATOR2, the approach is as follows:

- Use the calculated N fertilizer rates for the year 2000 at STONE plot level, based on estimates for N inputs by manure and N requirements by crops, using a balanced nitrogen approach
- Superimpose the IMAGE predictions in terms of relative changes in N fertilizer data for the various IMAGE crop categories for the Netherlands (upland crop and grass) at the level of a country to INITIATOR2 crops at STONE plot level.

This requires an allocation of the INITIATOR2 crops to those used in IMAGE at country level as given in Table 8.

N fertilizer input is available in terms of inputs in kgN/ha for the following crop types: upland crop, legumes, rice and grass. As an example, the relative change in N fertilizer input per crop type is given in Table 11 for the Netherlands. In INITIATOR2, we also assumed increased N use efficiency in relation to the assumptions involved in IMAGE related to the decrease in N fertilizer input.

Table 11 Trends in N fertilizer input in terms of ratios for major crop types between the year 2030 as compared to 2000 for the Netherlands (for 2000, ratios are 1.0)

Year	Ratios in N fertilizer input compared to 2000	
	Grass land	Upland crop
2030	0.629	1.024

3.5 Data sources used by IMAGE, MITERRA and INITIATOR

An overview of the data sources used by IMAGE, MITERRA and INITIATOR2 for the year 2000 is given in Table 12. The N excretion rates per animal category are different for each model and the detail increases with an increase in the number of animal categories considered, i.e. going from IMAGE to INITIATOR2. If the same source is used (e.g. FAO data for N fertilizer application rates by both IMAGE and MITERRA), country totals for these data should be equal.

For future predictions, the data sets used by either MITERRA and INITIATOR2 are the basis for the calculations, whereas the trends in animal numbers, crop areas, crop yields and fertilizer application rates are based on IMAGE and superimposed on these data as described before. GTAP/IMAGE output for the future is based on calibrations to FAO data in the past. N excretion rates per animal category are kept constant.

Table 12 Data sources used by IMAGE, MITERRA and INITIATOR2 for the year 2000

Data	IMAGE	MITERRA Europe	INITIATOR2
Animal numbers	FAO	RAINS	GIAB
N excretion rates per animal category	IMAGE: values per subcontinent	RAINS data: values per country	INITIATOR2: values for the Netherlands
Crop areas	FAO	CAPRI and own values	GIAB
Crop yields	FAO	FAO and own values	Own values
Fertilizer application	FAO	FAO	Balanced N approach

4 Model results

We present model results on a country basis and compare results of (i) MITERRA and INITIATOR2 for the Netherlands and (ii) IMAGE and MITERRA for 27 countries in Europe. The presented results include N fluxes (NH_3, N_2O and NO_x emissions, N leaching and N runoff) and CH_4 fluxes on country level in kton N/yr and in ktonCH$_4$/yr, respectively. More specifically, it includes:

- N surplus being the sum of N inputs by fertilizer, manure and deposition minus the N uptake
- N emission fluxes (NH_3, N_2O and NO_x) from housing systems, grass land and arable land (all agricultural land) and the total emission from agriculture (housing systems and agricultural land).
- N leaching/runoff from grass land, arable land and total agricultural land,
- CH_4 emission due to fermentation and manure storage. INITIATOR2 also calculates the CH_4 exchange by terrestrial ecosystems (net release from wetland and net sink in drained peat lands and mineral soils), but this is negligible compared to fermentation and manure storage and has been neglected.

4.1 Results for the Netherlands

4.1.1 Data used by MITERRA and INITIATOR2

The major differences affecting the INITIATOR2 and MITERRA output are (i) the agricultural area considered), (ii) the estimated N inputs by animal manure and mineral fertilizer and (iii) the emission factors for the various compounds considered (NH_3, N_2O, NO_x and CH_4). An overview of the data used for these input data by both models is given below.

Agricultural area: The used data for the agricultural area in the Netherlands by INITIATOR2 (GIAB database) and MITERRA (FAO data) is presented in Table 13. results show that the total agricultural area in MITERRA is approximately 100.000 ha less than in INITIATOR2 (approximately 5%), which is due to a clear underestimation of the grass land area.

Table 13 Data for the agricultural area in the Netherlands used by INITIATOR2 and MITERRA

Land use	Area (1000 ha)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Grass land	984	820	926	771
Arable land	967	1033	814	880
Agricultural land	1950	1853	1730	1651

Nitrogen inputs: An overview of the nitrogen excretion in housing and manure storage systems and by grazing and the related nitrogen application by animal manure and fertilizer on grass land and arable land is given in Table 14.

Table 14 Nitrogen excretion in housing and manure storage systems and by grazing and nitrogen application by animal manure and fertilizer in the Netherlands in 2000 and 2030 used by INITIATOR2 and MITERRA

Source	Land use	Nitrogen excretion/application (kton N/yr)			
		2000		2030	
		INITIATOR2	MITERRA	INITIATOR2	MITERRA
Nitrogen excretion					
Housing and storage		427	384	318	341
Grazing		108	122	87	97
Nitrogen input					
Animal manure	Grass land	190	96	162	89
	Arable land	124	212	74	184
Fertilizer	Grass land	205	162	122	102
	Arable land	100	138	86	78

The difference between the N excretion in housing and manure storage systems and the N input by animal manure application is mainly due to N emissions from the housing and manure storage systems. The estimated total N excretion both in the housing systems and in the field (by grazing animals) in the year 2000 is slightly higher by INITIATOR2 than by MITERRA (535 versus 506 kton N/yr), whereas the reverse is true in 2030 (405 versus 438 kton N/yr). Even though the total N application by animal manure is comparable for both models, the estimated application by INITIATOR2 is much higher on grassland than on arable land, while the opposite is true for MITERRA. The estimated total N fertilizer input in 2000 is comparable for INITIATOR2 and MITERRA, but the inputs in 2030 are higher for INITIATOR2. Overall, the differences are small except for the deviating inputs on grassland versus arable land.

Emission factors: An overview of the emission factors used for NH_3, N_2O, NO_x and CH_4 by both models is given in Table 15 in as far as a comparable modelling approach is used. Comparison of N_2O en NO_x emission factors in view of N application by manure and fertilizers is for example irrelevant, since INITIATOR2 derives N_2O emission on the basis of nitrification and denitrification rates and N_2O/N_2 ratios during these processes. In general, the emission factors are in the same range, except for the N_2O emission fraction from poultry in housing/manure storage systems, which is 4 times as high in MITERRA compared to INITIATOR2 (Table 15).

4.1.2 Nitrogen budgets and nitrogen fluxes to the atmosphere and to water at a national scale

Nitrogen budgets

Estimated N budgets for agricultural land for the whole of the Netherlands for the years 2000 and 2030 are quite comparable for INITIATOR2 and MITERRA (Table 16). The estimated total N inputs by both models are highly comparable both in 2000 and 2030. The largest differences occurs for the N input by manure application in 2030 which is higher in MITERRA compared to INITITOR2 due to a much lower reduction in N excretion.

Table 15 Average emission factors for NH_3, N_2O, NO_x (in % of the N excretion) as used in INITIATOR2 and MITERRA

Compound	Location	Source	Emission factors	
			INITIATOR2	MITERRA
NH_3-N	Grass land	Fertilizer	2.6	2.4
	Arable land	Fertilizer	2.6	2.4
	Grassland	Animal manure	9.8	13.7
	Arable land	Animal manure	15.0	13.3
	Housing/storage	Cattle	12.6	11.6
		Pigs	22.3	17.3
		Poultry	18.1	11.3
	Grazing	-	8.0	6.7
N_2O-N	Housing/storage	Cattle	0.35	0.14
		Pigs	0.25	0.73
		Poultry	0.91	3.7
NO_x-N	Housing/storage	Cattle	0.35	0.3
		Pigs	0.25	0.3
		Poultry	0.91	0.3

Table 16 N budgets for agricultural land for the Netherlands, estimated by INITIATOR2 and MITERRA for the years 2000 and 2030

N budget term	N flux (kton N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Fertilizer	305	300	208	180
Manure application	314	308	235	272
Organic products	11	0	9.4	0
Grazing	108	122	87	97
Deposition	65	66	52	54
Fixation	16	7.8	15	7.0
Total input	820	803	606	610
N mineralization	69	0	63	0
Crop removal	425	337	385	343
Surplus	464	466	284	267

In INITIATOR2, we assume an efficiency increase that is not assumed in MITERRA. Furthermore, the N balance by INITIATOR2 includes more sources, i.e. organic products and N mineralization of drained peat soils. The latter flux is considerable. Nevertheless, the net surplus derived by both models is quite comparable due to an estimated higher N uptake by INITIATOR2 as compared to MITERRA.

Gaseous emissions of ammonia, nitrous oxide and nitrogen oxides

Results of the estimated gaseous emissions of ammonia, nitrous oxide and nitrogen oxides by INITIATOR2 and MITERRA for the years 2000 and 2030 at national scale are given in Table 17, 18 and 19, respectively. A distinction is made in emissions from housing systems and from the field, with a division in grass land and arable land. Field emissions are due to animal manure application (near 75%) while the remaining part is almost equally divided over emissions due to grazing and fertilizer application. This distinction can not be quantified by INITIATOR2 in case of N_2O and NO_x emissions, as these emissions are assessed as a function of nitrification and denitrification in response to the total N input. Therefore we consistently used the distinction in field emissions from grass land and arable land.

Table 17 Calculated total ammonia emissions from housing systems and agricultural land for the Netherlands by INITIATOR2 and MITERRA for the years 2000 and 2030

Location	NH_3 emissions (kton NH_3-N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Housing systems	70	52	51	46
Grass land	33	25	26	21
Arable land	22	31	13	26
Agricultural land	55	56	39	47
Total agriculture	125	108	90	93

Table 18 Calculated total nitrous oxide emissions from agricultural land for the Netherlands by INITIATOR2 and MITERRA for the years 2000 and 2030

Location	N_2O emissions (kton N_2O-N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Housing systems	1.7	3.2	1.4	3.0
Grass land	12.6	5.9	7.8	4.6
Arable land	5.6	5.8	3.6	4.5
Agricultural land	18.2	11.8	11.3	9.2
Total agriculture	20.0	15.0	12.7	12.2

Table 19 Calculated total nitrogen oxides emissions from agricultural land for the Netherlands by INITIATOR2 and MITERRA for the years 2000 and 2030

Location	NO_x emissions (kton NO-N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Housing systems	1.7	1.9	1.4	1.7
Grass land	8.8	9.1	5.1	7.2
Arable land	4.6	0.7	3.0	0.4
Agricultural land	13.5	9.8	8.0	7.6
Total agriculture	15.2	11.7	9.4	9.3

In the year 2000, the estimated total NH_3 emissions by INITIATOR2 is approximately 20% higher than the estimate by MITERRA, which is due to a higher estimated emission from the housing and manure storage systems. Even though the emissions from total agricultural land are comparable, the emissions from grassland are lower in INITIATOR2 than by MITERRA, whereas the reverse is true for arable land (Table 17). This is almost completely due to a different assignment of the N inputs to grassland and arable land (Table 14) and not so much to a difference in ammonia emission factors, which are quite comparable (Table 15). In the year 2030, total NH_3 emissions are comparable due to an estimated much stronger decrease in N excretion in the housing systems by INITIATOR2 than by MITERRA (Table 14).

In the year 2000, the estimated total N_2O and NO_x emissions by INITIATOR2 are approximately 40% higher than the estimate by MITERRA (Table 18 and 19). For N_2O, this is due to a higher (twice as high) estimated emission from grassland (Table

18). This is mainly caused by a nearly twice as high N input to grassland in INITIATOR2 (Table 14) and is partly due to an overall higher emission fraction (calculated from nitrification and denitrification). The overall higher emission fraction is specifically clear for arable land, where the estimated N_2O emissions by both models are equal, whereas the N input to arable land is lower (Table 14). For NO_x, the difference in emissions is due to a much higher (seven times as high) estimated emission from arable land by INITIATOR2 (Table 19). This large deviation is mainly caused by a very low NO_x emission factor from animal manure in MITERRA (0.12 % for NO_x as compared to 2.12 % for N_2O). In INITIATOR2, the ratio of NO_x to N_2O is near 40%, being an average ratio that can be derived from a comparison of results of 1008 N_2O and 189 NO emission measurements from agricultural fields presented by Stehfest and Bouwman (2006). The estimated N_2O emissions from housing and manure storage systems is lower in INITIATOR2 than by MITERRA, in line with the lower emission fractions for pigs and poultry (Table 15). As with NH_3, estimated total N_2O and NO_x emissions in the year 2030 by both models are comparable due to an estimated much stronger decrease in N excretion in the housing systems by INITIATOR2 than by MITERRA (Table 14).

The estimated total methane CH_4 emissions in the year 2000 are 413 kton CH_4/yr by INITIATOR2 and 479 kton CH_4/yr by MITERRA, implying an approximately 20% higher estimate by MITERRA. In the year 2030, the deviation is even larger, i.e. 310 kton CH_4/yr by INITIATOR2 and 394 kton CH_4/yr by MITERRA, implying an approximately 30% higher estimate by MITERRA.

Leaching and runoff of nitrogen

Results of the calculated nitrogen leaching and runoff on a national scale is given in Table 20 and 21, respectively. The estimated N leaching by MITERRA in the year 2000 is approximately 20% higher than by INITIATOR2, but the results are quite comparable by both models in 2030 (Table 20).

Table 20 Calculated total nitrogen leaching for the Netherlands by INITIATOR and MITERRA in 2000 and 2030

Land use	N leaching (kton N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Grass land	45	47	24	20
Arable land	44	61	28	33
Agricultural land	88	108	53	53

The reduction in N leaching in the period 2000 to 2030 is larger in MITERRA than in INITIATOR2, even though the reduction in N excretion in the housing systems by INITIATOR2 is larger than by MITERRA (see before). Estimates for N runoff are nearly twice as high by INITIATOR2 than by MITERRA (Table 21). It illustrates the uncertainty in those estimates, which are the result of all the N processes taking place before N is removed from the soil system, either by leaching or runoff.

Table 21 Calculated total nitrogen runoff for the Netherlands by INITIATOR and MITERRA in 2000 and 2030

Land use	N runoff (kton N/yr)			
	2000		2030	
	INITIATOR2	MITERRA	INITIATOR2	MITERRA
Grass land	27	9.9	16	7.4
Arable land	16	9.6	10	6.9
Agricultural land	44	19.5	26	14.3

4.1.3 Ammonia emissions to the atmosphere and nitrogen concentrations in leachate to ground water at regional scale

With respect to the emission of green house gases, such as N_2O and CH_4, it is crucial to know whether total emissions for the area considered (e.g. country or continent) are correct. Accurate information on the spatial distribution of the emissions is less relevant. The latter aspect is, however, crucial when assessing the risk of elevated NH_3 emissions, and related N deposition, and of N leaching and N runoff in view of eutrophication impacts on terrestrial and aquatic ecosystems. Here, aggregation of input data for large areas may cause accurate average N deposition and N leaching levels, but a strong deviation in the area exceeding critical N deposition loads or critical N concentrations in ground water and surface water.

A comparison of the predicted N inputs by manure application, fertilizer application, grazing and total N inputs by INITIATOR2 and MITERRA per NUTS2 region for the year 2000 shows that results are highly comparable and generally deviate by less than 10% (Figure 2). A comparison of the predicted total NH_3 emissions by INITIATOR2 and MITERRA per NUTS2 region for the year 2000 shows that results, in line with the national result, generally deviate by less than 20%. However, while predicted total N leaching at the national scale by INITIATOR2 and MITERRA is comparable, the variation at NUTS2 level is considerable and can be even more than 100% (Figure 3). The differences are much larger for N_2O and NO_x emissions than for NH_3 emissions, but this is in line with the national larger differences (Figure 3).

Even tough the total NH_3 emissions at NUTS2 level are quite comparable, INITIATOR2 predicts a large spatial variation within each NUTS2 region, that can deviate largely from the NUTS2 average emissions as shown in Figure 4. The variation in NH_3 emissions affects the N deposition, mainly resulting from NH_3 emissions in agriculture and NO_x emissions by traffic and industry. For N leaching, the comparability of results was only high at national level, while there is a large spatial variation both between and within each NUTS2 region. This is illustrated in Figure 5 for the predicted NO_3 concentrations in leachate to ground water. The area exceeding critical N deposition loads and critical NO_3 concentrations in groundwater (50 mgNO_3/l) is largely affected by variability in N deposition and N leaching levels.

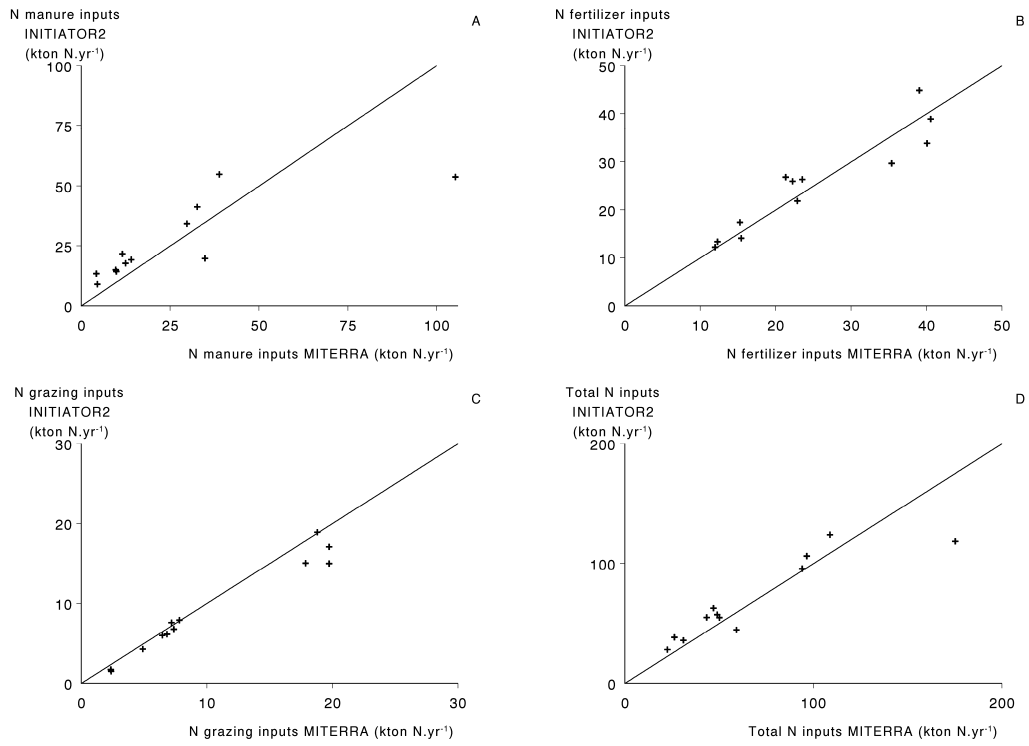

Figure 2 Comparison of N inputs by manure application (A) , fertilizer application (B), grazing (C) and total N inputs (D) by INITIATOR2 and MITERRA per NUTS2 region in the Netherlands for the year 2000

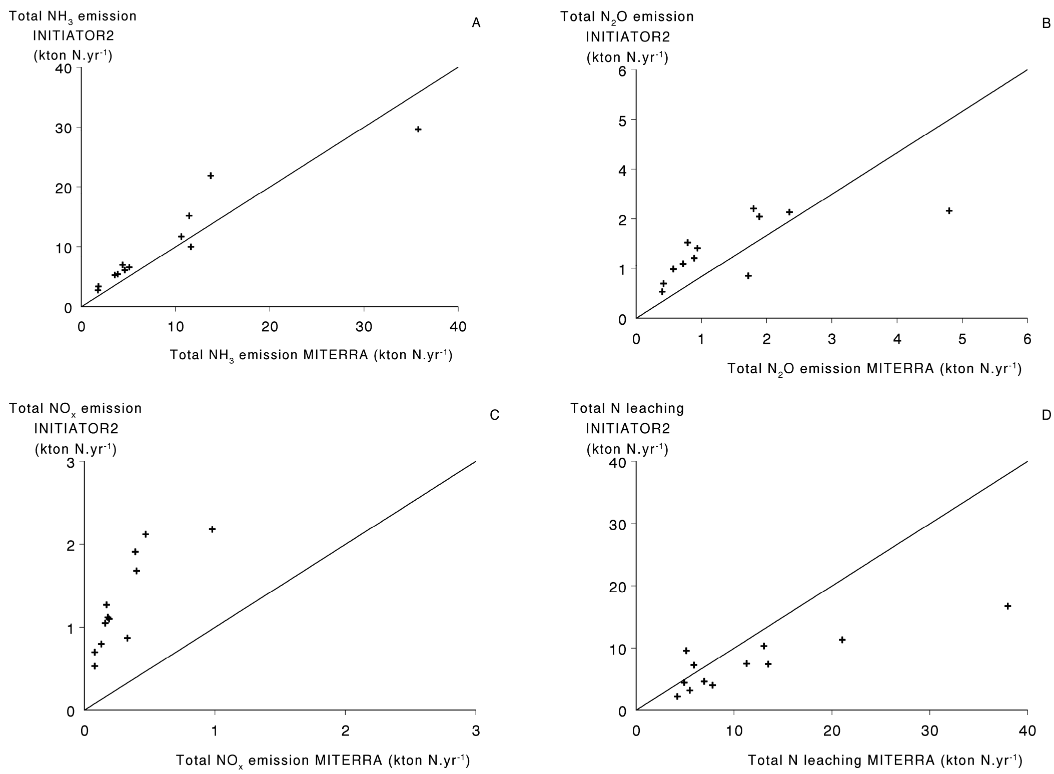

Figure 3 Comparison of total NH_3 emissions (A), N_2O emissions (B) NO_X emissions (C) and N leaching (D) by INITIATOR2 and MITERRA per NUTS2 region in the Netherlands for the year 2000

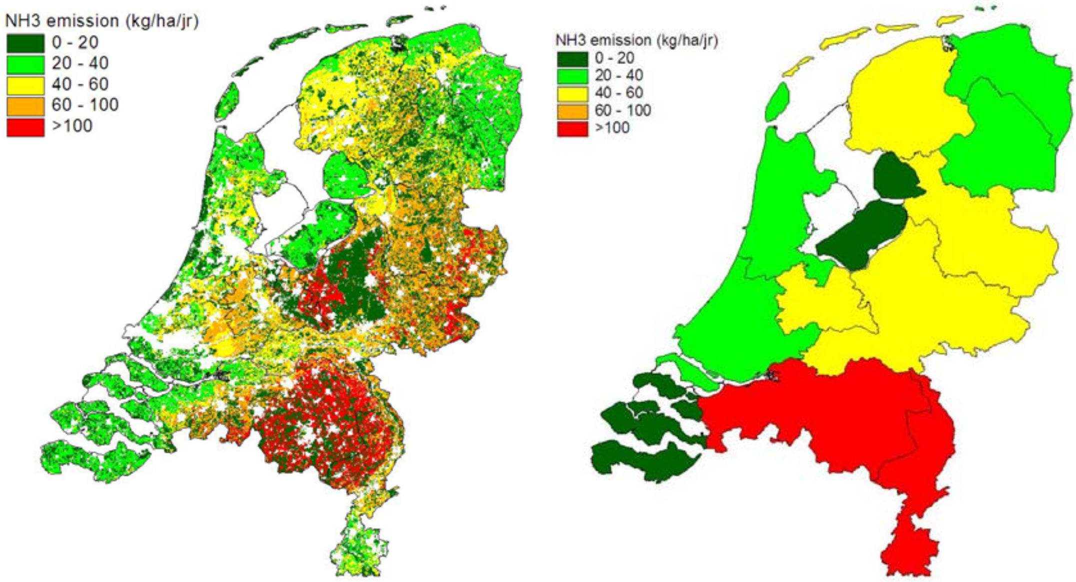

Figure 4 Geographic variation in total NH_3 emissions as derived by INITIATOR2 per STONE plot (Left) and by MITERRA per NUTS2 region (Right) in the Netherlands for the year 2000

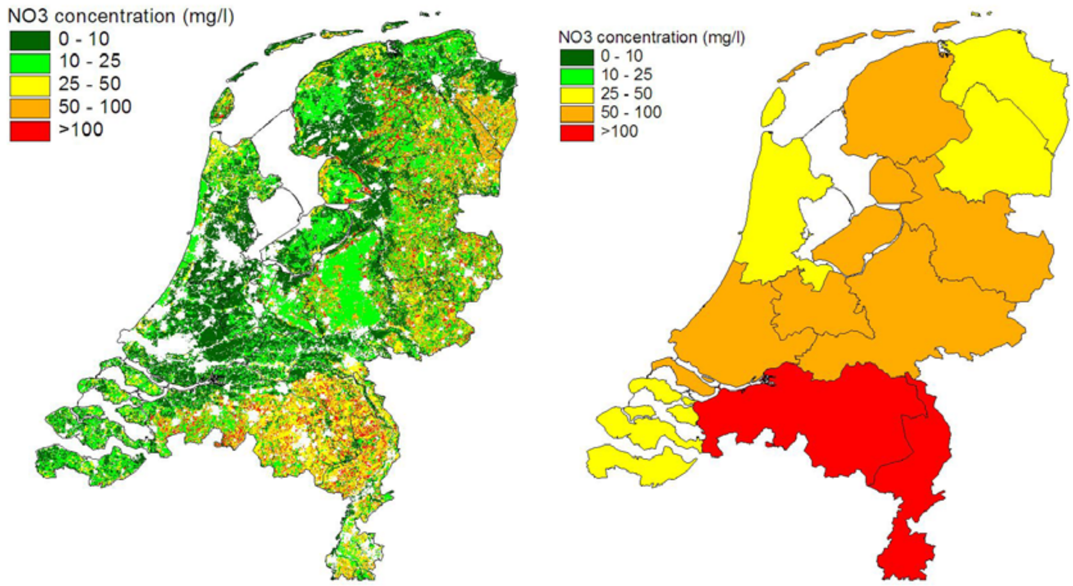

Figure 5 Geographic variation in NO_3 concentrations in leachate to ground water as derived by INITIATOR2 per STONE plot (Left) and by MITERRA per NUTS2 region (Right) in the Netherlands for the year 2000

We estimated the N deposition by using the NH_3 emission results from both models while (i) using an emission-deposition transfer matrix in INITIATOR (see before), while adding available background NO_x deposition data per STONE plot and (ii) assuming that NH_3 deposition in each NUTS2 region is 55% of the NH_3 emission (average value for the Netherlands) and adding the same background deposition per NUTS2 region. The resulting present N loads were compared with available critical N loads for nature target types in the Netherlands (Van Dobben & van Hinsberg, 2008). The exceedance of the critical N load thus derived is given in Table 22, in terms of (i) the area exceeding the critical N load, (ii) the accumulated N exceedance, being the product of area and exceedance for all areas where the N deposition in 2000 exceeds the critical N deposition and (iii) the average exceedance, being equal to the accumulated exceedance divided by the area where N exceedance occurs. The exceedance of the critical N leaching is also given in Table 22, where the criterion is the NO_3 concentration in the leachate of 50 mg NO_3/l. Here the accumulated and average exceedance refers to the N leaching in excess of the leaching related to a critical NO_3 concentration of 50 mg NO_3/l.

Results show that the area exceeding critical N loads by INITIATOR2 and MITERRA is highly comparable but the predicted average level of exceedance is higher by INITIATOR2 in line with the predicted higher NH_3 emissions. The area exceeding critical NO_3 concentrations in leachate tot ground water and the accumulated and average level of exceedance of N leaching rates is, however, largely affected by the spatial aggregation, despite the comparable N leaching rates at national scale. Here the averaging procedure by MITERRA most likely causes an overestimate of the area exceeding critical NO_3 concentrations, considering the validity status of INITIATOR2 with respect to NO_3 concentrations.

Table 22 Calculated exceedances of critical N loads in the Netherlands by INITIATOR and MITERRA in the year 2000

Type of exceedance	Model	Exceedance		
		Area (%)	Accumulated (ton/yr)	Average (kg/ha/yr)
Deposition	INITIATOR2	86	5174	8.5
	MITERRA	87	4294	6.4
Leaching	INITIATOR2	27	11	20
	MITERRA	70	51	37

4.2 Results for EU 27

4.2.1 Data used by IMAGE and MITERRA

As with the results for the Netherlands, major differences affecting the IMAGE and MITERRA output for Europe (EU 27) are (i) the agricultural area considered), (ii) the estimated N inputs by animal manure and mineral fertilizer and (iii) the emission factors for the various compounds considered (NH_3, N_2O, NO_x and CH_4). An overview of the data used for these input data by both models is given below.

Agricultural area: The agricultural area in IMAGE in 2000 and 2030 is based on agricultural production data for the year 2000 (FAO, 2007)and predictions for 2030 (Bruinsma, 2003). The agricultural area in MITERRA is based on the land cover/land use map of CORINE (CLC2000). In Table 23 the used crop areas are displayed. Results show a much larger agricultural land area in IMAGE than in MITERRA, due to the inclusion of natural grassland, fallow, set aside, non-food crop production etc in agricultural land by IMAGE. The differences are much smaller, specifically in 2030, when this basis is excluded (Table 23).

Table 23 Land areas used in IMAGE and MITERRA for EU 27 in 2000 and 2030

Land use	Area (Mha)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Grass land	68.2	40.7	60.5	35.5
Arable land	131.7	100.9	119.3	106.9
Agricultural land	199.9	141.6	179.7	142.4
Other *)		32.7		30.0
Total	199.9	174.3	179.7	172.4

*) natural grassland, fallow, set aside, non-food crop production etc. For IMAGE, fallow land is included in agricultural land, while other grassland and non-food crops are not accounted for.

Nitrogen inputs: An overview of the nitrogen excretion in housing and manure storage systems and by grazing and the related nitrogen application by animal manure and fertilizer is given in Table 24. Unlike the comparison on a national scale (see Table 14), no differentiation is made in grassland and arable land, since IMAGE does not give results on the basis of this distinction. In general, overall results are quite comparable. The summed N input by manure is closer to the total N excretion in case of IMAGE than in the case of MITERRA.

Table 24 Nitrogen excretion in housing and manure storage systems and by grazing and nitrogen application by animal manure and fertilizer in 2000 and 2030 used by IMAGE and MITERRA

Source	Nitrogen flux (kton N/yr)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Nitrogen excretion				
Housing and storage	5238	6812	4599	5943
Grazing	4609	3560	3141	2632
Nitrogen input				
Fertilizer	11223	11302	10312	11558
Animal manure	4191	4785	3679	4162

A comparison of the N inputs per country for the year 2000 shows a very high correlation for animal manure and fertilizer inputs (R^2 = 0.99), whereas the correlation with N fluxes in housing and storage systems and N inputs by grazing is less (R^2 = 0.84-0.99) as shown in Figure 6. IMAGE has often less manure in animal houses than MITERRA and more in the meadow; due to application of European-scale housing and grazing fractions.

Emission factors: Table 25 shows the emission coefficients used for NH_3, NO_x and N_2O. For NH_3, emission fractions related to fertilizer application are on average higher for IMAGE than MITERRA whereas the reverse is true for manure application while grazing emission fractions are comparable. The NH_3 emission fractions of NH_3 for MITERRA are based on country specific data included in the RAINS/GAINS model, whereas the data for IMAGE are based on Bouwman et al. (1997) for NH_3 volatilization from manure storage and manure excreted during grazing and on Bouwman et al. (2002b) for NH_3 volatilization from fertilizer and animal manure application.

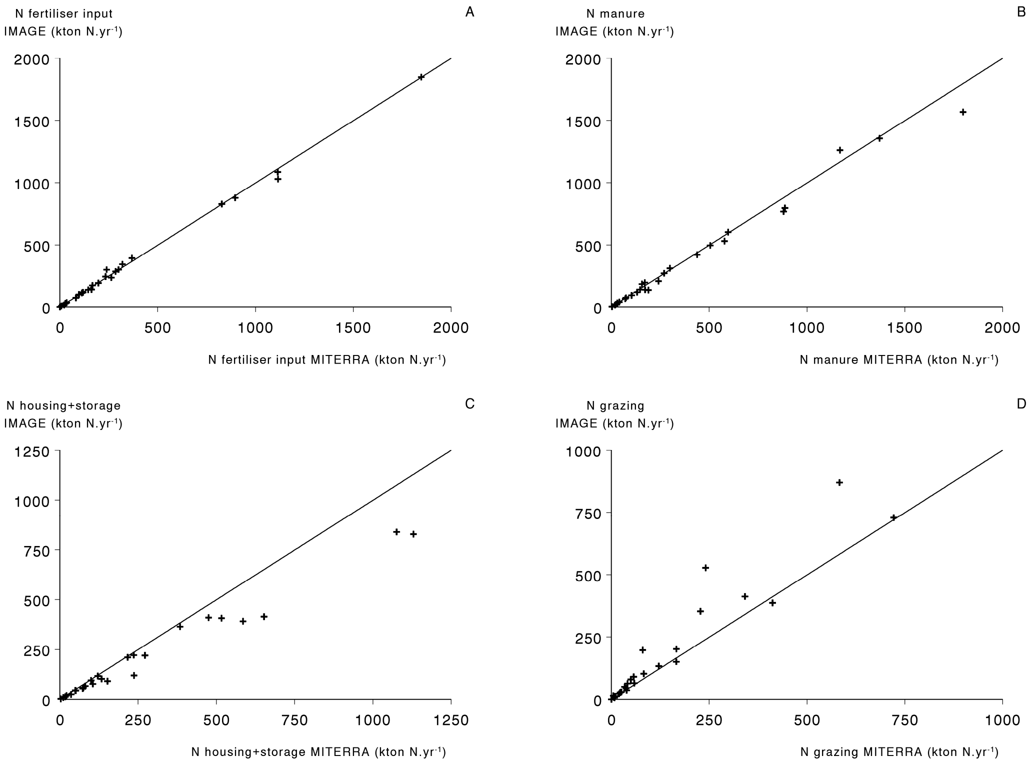

Figure 6 Comparison of the N inputs by IMAGE and MITERRA per country for the year 2000 for N fertilizer inputs (A), N animal manure inputs (B), N excretions in housing and storage systems (C) and N inputs by grazing (D)

Bouwman et al. (2002b) used a residual maximum likelihood (REML) model based on (i) factors related to agricultural management, including crop type, fertilizer type, and fertilizer application technique (broadcasting, incorporation, injection, solution), and (ii) factors related to environmental conditions (climate, soil pH, and CEC), using a data set of about 1700 measurement series. The data are included on a 0.5 x 0.5 degree resolution. Results are aggregated to the country scale to derive N emission fractions. A comparison of the NH_3 emission fractions related to manure application, fertilizer application and grazing per country shows a considerable scatter and in case of fertilizer application a consistently higher emission fraction by IMAGE as compared to MITERRA (Figure 7). For N_2O emissions, IMAGE has a fixed number for housing and grazing emission fractions of 1% and 2%, respectively, whereas MITERRA has a large variation, depending on the country involved, while the reverse is true for N_2O emission fractions from manure and fertilizer application (Figure 8). MITERRA uses a constant emission fraction of 1.25%, whereas IMAGE uses a regression based approach based on the results of a collection of N_2O emission measurements from agricultural fields, reported in Bouwman et al. (2002a). Results are aggregated to the country scale to derive N_2O-N emission fractions.

Table 25Average emission factors for NH_3, N_2O and NO_x in IMAGE and MITERRA for the year 2000 (in % of available N)

Element	Location	Manure category	Model	
			IMAGE	MITERRA
NH_3-N	Grass land	Fertilizer	7.1	5.5
	Arable land	Fertilizer	(7.1) [1)]	5.2
	Grassland [1)]	Animal manure	16.3	20.4
	Arable land	Animal manure	(16.3) [1)]	18.1
	Housing and storage	Cattle	20	17
		Pigs	(20) [2)]	22
		Poultry	(20) [2)]	22
	Grazing		6.9	6.8
N_2O-N	Grass land	Fertilizer	2.3	1.6
	Arable land	Fertilizer	0.4	1.4
	Grassland	Animal manure	2.3	1.8
	Arable land	Animal manure	0.4	1.6
	Housing and storage	Cattle	1	0.8
		Pigs	(1) [2)]	0.4
		Poultry	(1) [2)]	0.5
	Grazing		2	2
NO_x-N	Grass land	Fertilizer	1.0	0.3
	Arable land	Fertilizer	1.0	0.3
	Grassland	Animal manure	1.0	0.3
	Arable land	Animal manure	1.0	0.3
	Housing and storage	Cattle	0	0.3
		Pigs	0	0.3
		Poultry	0	0.3
	Grazing		0.5	0.3

[1)] Value is average for grassland and arable land
[2)] Value is average for cattle, pigs and poultry

In IMAGE, NO_x emissions from housing and manure storage systems are neglected, whereas MITERRA assumes an emission fraction of 0.3%. For NO_x emissions due to manure and fertilizer application and grazing, both IMAGE and MITERRA use fixed numbers, but the values in IMAGE are much larger (1% for manure and fertilizer application and 0.5% for grazing) than in MITERRA (0.3%). The value used in MITERRA is based on Skiba et al. (1997), whereas the IMAGE fractions are based on 99 NO emission measurements from agricultural fields, reported in Bouwman et al. (2002a).

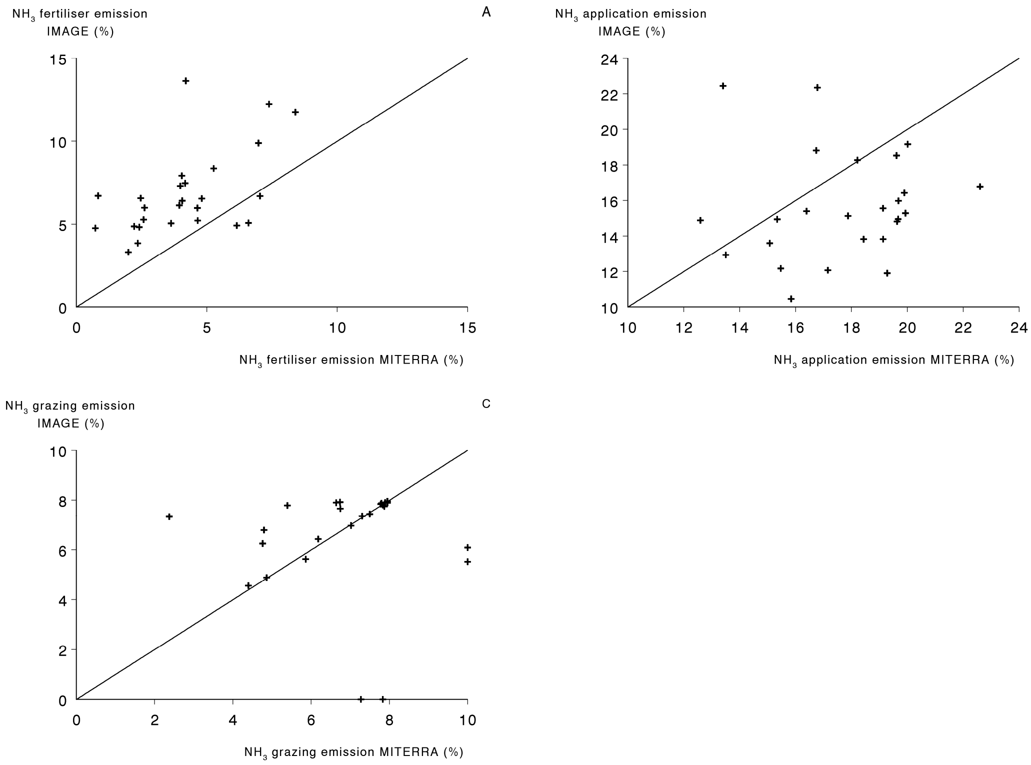

Figure 7 Comparison of the NH_3 emission fractions per country by IMAGE and MITERRA related to fertilizer application (A), manure application (B) and grazing (C)

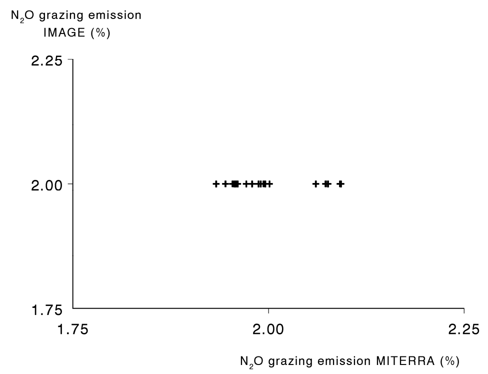

Figure 8 Comparison of the N_2O-N emission fractions per country by IMAGE and MITERRA related to grazing

4.2.2 Nitrogen budgets and nitrogen fluxes to the atmosphere and to water at a European scale

Nitrogen budgets

Estimated N budgets for agricultural land for Europe (EU27) for the years 2000 and 2030 are quite comparable for IMAGE and MITERRA (Table 26). Total N inputs compare within 10%, although individual sources such as grazing and deposition deviate up to 30%, The total N inputs are approximately 2750 kton N larger in

IMAGE in the year 2000. The larger input in 2000 is compensated by a larger N uptake in IMAGE, leading to a comparable N surplus at the European scale. In 2030, the differences in total N inputs are almost negligible, due to an estimated increase in N fertilizer input by MITERRA in response to an increase in N crop uptake. The increase in N fertilizer input is because MITERRA did not assume an increase in N use efficiency in the period 2000-2030. Such an increase was however assumed in IMAGE and consequently, both the estimated N fertilizer input and N crop uptake decreases in 2030 as compared to 2000. In 2030, the lowering in N fertilizer input by IMAGE causes a slightly smaller predicted N surplus by this model as compared to MITERRA.

Table 26 N budgets for agricultural land for EU 27 by IMAGE and MITERRA for the years 2000 and 2030

Input	N flux (kton N/yr)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Fertilizer application	11223	11302	10312	11558
Manure application	4191	4785	3679	4162
Grazing	4609	3560	3141	2632
Deposition	2789	2015	1949	1812
Fixation	1385	832	1285	785
Total input	24179	22494	20366	20949
Crop removal	13500	10635	12270	11118
Surplus	10679	11860	9016	9832

Gaseous emissions of ammonia, nitrous oxide and methane

Results of the estimated gaseous emissions of ammonia, nitrous oxide and nitrogen oxides by INITIATOR2 and MITERRA for the years 2000 and 2030 are given in Table 27, 28 and 29, respectively.

Results for the total emissions of ammonia for EU27 are highly comparable for MITERRA and IMAGE, both in 2000 and 2030 (Table 27). Results show lower NH_3 emissions from housing and manure storage systems and from manure application, but this is compensated by higher emissions due to fertilizer application and grazing.

Table 27 Calculated total ammonia emissions from housing systems and agricultural land for EU 27 by IMAGE and MITERRA for the years 2000 and 2030

Emission type	NH_3 emissions (kton NH_3-N/yr)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Housing and storage	1048	1279	920	1131
Fertilizer application	798	540	727	568
Manure application	683	823	594	711
Grazing	319	231	215	174
Total agriculture	2848	2873	2456	2584

The calculated total emissions of nitrous oxides for EU27 are higher by IMAGE compared to MITERRA, both in 2000 and 2030 (Table 28). This is mainly due to higher N_2O emissions caused by manure and fertilizer application. The differences are smaller however, when the indirect emissions, included in MITERRA and not in IMAGE, are accounted for (Table 28).

Table 28 Calculated total nitrous oxide emissions from housing systems and agricultural land for EU 27 by IMAGE and MITERRA for the years 2000 and 2030

Emission type	N_2O emissions (kton N_2O-Nyr)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Housing and storage	52	54	46	46
Manure and fertilizer application	289	197	258	193
Grazing	92	66	63	49
Total agriculture	434	318 (374)[1]	367	288 (343)[1]

[1)] The value in brackets is the total N_2O emission calculated by MITERRA including also (indirect) N_2O emissions due to biological N fixation (10 kton N/yr both in 2000 and 2030), N leaching (21 kton N/yr in 2000 and 18 kton N/yr 2030) and ammonia emission (30 kton N/yr in 2000 and 27 kton N/yr 2030)

Nitrogen oxides emissions:

The calculated total emissions of nitrogen oxides for EU27 are nearly twice as high by IMAGE as compared to MITERRA, both in 2000 and 2030 (Table 29). This is completely due to higher N_2O emissions caused by manure and fertilizer application.

Table 29 Calculated total nitrogen oxides emissions from housing systems and agricultural land for EU 27 by IMAGE and MITERRA for the years 2000 and 2030

Emission type	NO_x emissions (kton NO_x -N/yr)			
	2000		2030	
	IMAGE	MITERRA	IMAGE	MITERRA
Housing and storage systems	0	36	0	31
Soil emission grazing	23	25	16	21
Soil emission manure +fertilizer	196	32	169	33
Total agriculture	219	93	184	85

The difference in NO_x emissions due to manure and fertilizer application is completely due to the much larger NO_x emission fractions in IMAGE (1% for manure and fertilizer application and 0.5% for grazing) than in MITERRA (0.3%), as given before. NO_x emissions from housing and manure storage systems, which are only included in MITERRA compensate only slightly for the difference.

CH_4 emissions by MITERRA for EU 27 are 9848 kton CH_4/yr in 2000 and 7935 kton CH_4/yr in 2030. In IMAGE, CH_4 emissions are not calculated on a country basis but only for regions, including Western Europe and Eastern Europe. The total CH_4 emissions for Europe as a whole, estimated by IMAGE are 11429 kton CH_4/yr in 2000 and 9276 kton CH_4/yr in 2030. Considering the difference in area involved these estimates are quite comparable.

Leaching and runoff of nitrogen

The calculated sum of total nitrogen leaching and runoff on a European scale is much higher (nearly twice as high) by IMAGE than by MITERRA (Table 30). Since IMAGE does not predict nitrogen leaching and runoff separately, a comparison can only be made for the sum of both fluxes. The estimated reduction in N leaching and N runoff in the period 2000-2030 is 25% in IMAGE and 15% in MITERRA, making the difference less in the year 2030.

Table 30 Calculated total nitrogen leaching for the EU 27 by IMAGE and MITERRA in 2000 and 2030 for all agricultural land

N leaching (kton N/yr)			
2000		2030	
IMAGE	MITERRA	IMAGE	MITERRA
5945	2811	4443	2398

Considering a comparable N surplus by IMAGE and MITERRA and a comparable N emission (the sum of NH_3, N_2O and NO_x emission, being dominated by NH_3 emission) implies that the difference between IMAGE and M ITERRA is mainly due to differences in N leaching/runoff fractions, dividing the N surplus in N_2 emissions on one hand and N leaching/runoff on the other hand. This illustrates the uncertainty in those leaching fractions.

4.2.3 Nitrogen budgets and nitrogen fluxes to the atmosphere and to water at a national and regional scale

A comparison of the predicted NH_3 emissions by IMAGE and MITERRA per country for the year 2000 (Figure 9) shows a limited correlation for N emissions from housing and storage systems and from fertilizer inputs, whereas the correlation with the emissions from animal manure inputs plus grazing and the total NH_3 emission is very high (R^2 = 0.99 and R^2 = 0.98, respectively). A comparison of the N_2O emissions per country for the year 2000 shows a reasonable correlation for the emissions from housing and storage systems and for the total N_2O emission but the correlation with the N_2O emissions from fertilizer and manure inputs and from grazing is limited (Figure 10). A comparison of the NO_x emissions per country for the year 2000 shows no correlation, neither for the soil emission due to manure and fertilizer application nor for the total emissions that are almost completely determined by it (Figure 11).

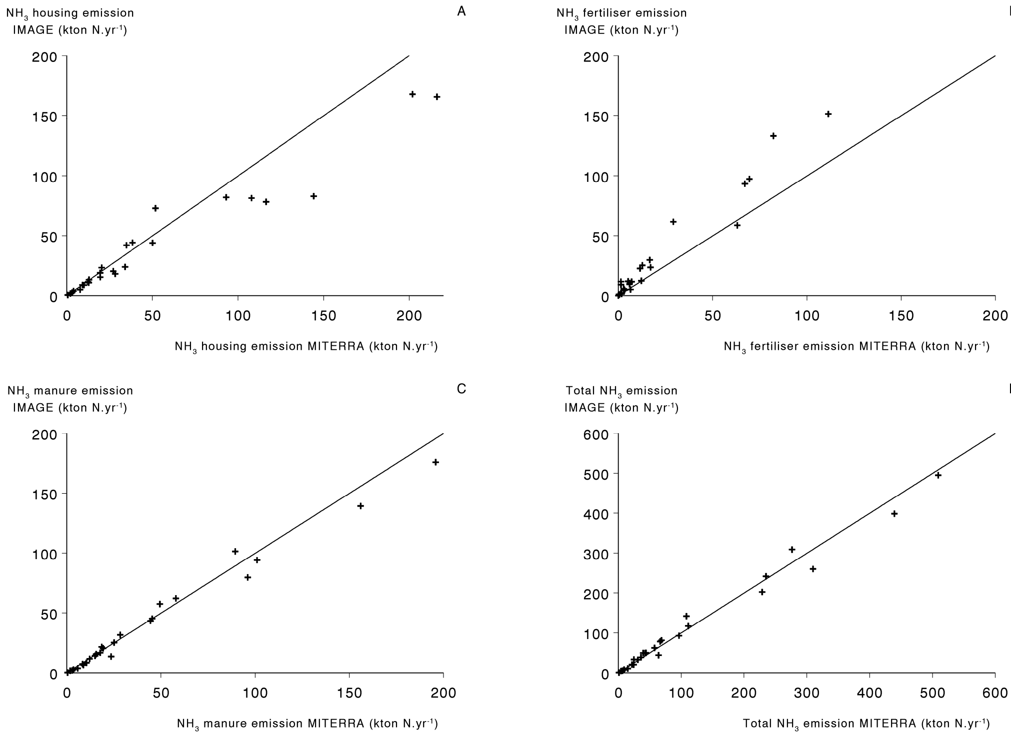

Figure 9 Comparison of NH_3 emissions by IMAGE and MITERRA per country for the year 2000 for housing emissions (A), fertilizer emissions (B), animal manure emissions plus grazing (C) and total emissions (D)

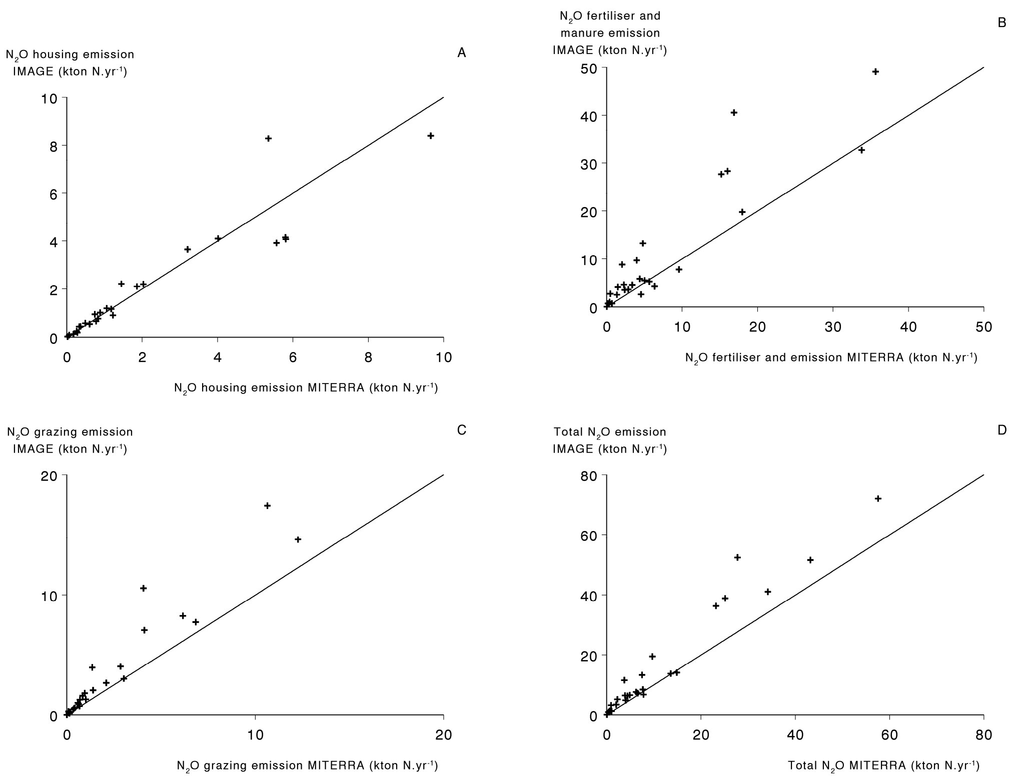

Figure 10 Comparison of the N_2O emissions per country by IMAGE and MITERRA related to housing (A), fertilizer and manure application (B) and grazing (C) and total emissions (D)

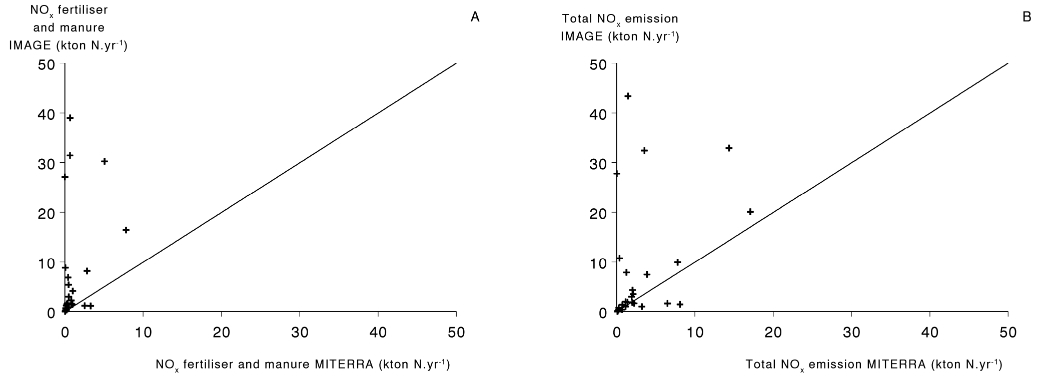

Figure 11 Comparison of the NO_X emissions per country by IMAGE and MITERRA related to fertilizer and manure application (A) and total emissions (B)

The systematic difference in leaching fractions is further illustrated by the comparison between the sum of N leaching and runoff per country by IMAGE and MITERRA, showing a high correlation but a systematic difference (Figure 12). Even tough the total NH_3 emissions at country level by IMAGE and MITERRA are very comparable (Figure 9D), MITERRA predicts a considerable spatial variation for NUTS2 regions within each country, that can deviate largely from the IMAGE average country emissions as shown in Figure 13. As with the results for the Netherlands, the variation in NH_3 emissions will affect the N deposition and thereby the exceedance of critical N loads at the European scale. For policy purposes reasons, however, the exceedance of national emission ceilings (NEC) is most relevant, and here the difference in results of IMAGE and MITERRA is very small as shown in Figure 14, since country NH_3 emissions are highly comparable. In general, NEC ceilings for 2010 (http://www.eea.europa.eu/highlights/more-eu-member-states-to-miss-2010-air-pollutant-limits/nec-status-preliminary-results-2008-data.pdf) are above the estimated NH_3 emissions calculated for the year 2000. One has to be aware of the fact that approximately 7% of the NH3 emissions come from non agricultural sources, implying that the actual emissions are 7% larger.

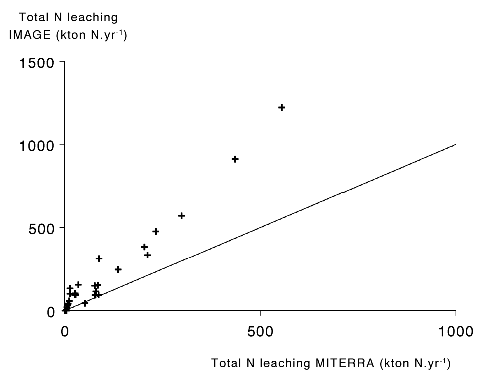

Figure 12 Comparison of the sum of N leaching and runoff per country by IMAGE and MITERRA

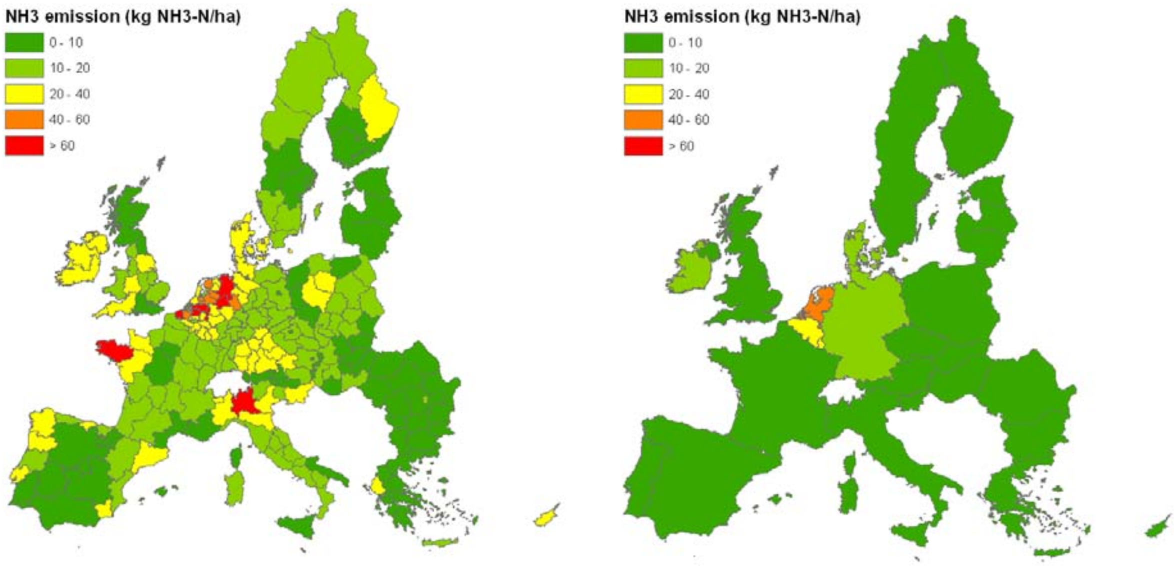

Figure 13 Geographic variation in total NH_3 emissions as derived by MITERRA per NUTS2 region (left) and by IMAGE per country (right) for EU27 for the year 2000

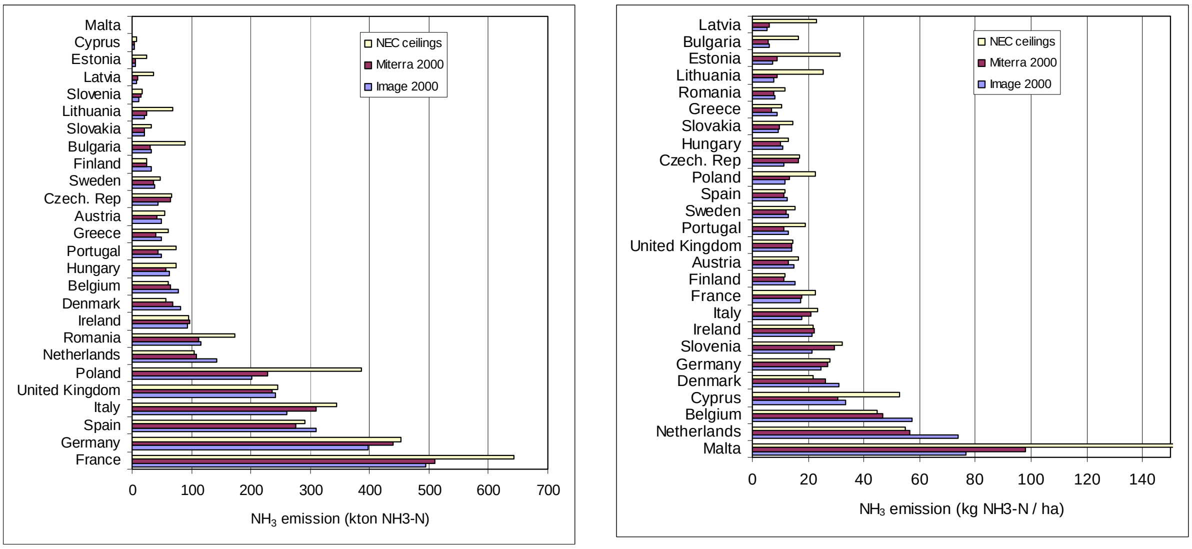

Figure 14 Comparison of national ammonia emission ceilings in kton NH_3-N (left) and in kg NH_3-N/ha (right) with estimates of the ammonia emissions in 2000 per country by MITERRA and by IMAGE

In general NH_3 emissions per hectare are between 20-40 kg NH_3-N. Exceedances occur for Belgium, Denmark, the Netherlands and very slightly for Finland and Spain when using IMAGE. The calculated exceedances are higher with IMAGE. For countries near or above the NEC a more accurate assessment is needed. For example, in the Netherlands, the NEC is 128 kton NH_3, being equal to 105 kton NH_3-N, while the estimates by IMAGE, MITERRA and INITIATOR2 are 142, 108 and 125 kton NH_3-N, respectively. Both INITIATOR2 and MITERRA estimates compare reasonably well with the formal assessments in the Netherlands, being 115 kton NH_3-N.

5 Discussion and conclusions on the impacts of different model approaches

This report focused on the comparison of model results developed for application on a global scale (IMAGE), European scale (MITERRA) and national scale (INITIATOR2). Results show that on the scale for which the models are developed, differences are relatively small. This holds specifically for the results at EU 27 level by IMAGE and MITERRA, but to a lesser extent for the results for the Netherlands by MITERRA and INITIATOR2. However, at more detailed level, differences can be large and this may largely affect estimates of the risk of elevated N deposition, as a results of elevated NH_3 emissions, and of N leaching and N runoff in view of impacts on terrestrial and aquatic ecosystems. Both aspects are discussed below.

5.1 Spatially aggregated results for nitrogen fluxes to atmosphere and water

IMAGE is developed to assess, amongst others, N fluxes and GHG emissions at the sub-continental scale and results at this level (i.e. at EU 27 level) are very comparable with those derived by the MITERRA model. MITERRA uses more detailed data within EU 27, i.e. at NUTS2 level, as compared to IMAGE that uses country data. Nevertheless, the comparison of aggregated results at country level is also quite comparable between IMAGE and MITERRA, with the exception of NO_x emissions and N leaching plus runoff. The differences in NO_x emissions are not so much caused by differences in the spatial resolution of input data but by differences in the used NO_x emission fractions.

In general, the impact of spatial aggregation is likely to be limited at an aggregated level when comparing emission fraction based models, unless the emission fraction is a function of features that vary in space, such as land cover, soil type or climatic variables. Use of more spatially explicit data may then cause significant differences between model outcomes. The interesting feature is now that where MITERRA uses constant fractions for NH_3, N_2O and NO_x emissions, IMAGE uses fractions based on factors related to (i) climate, such as annual average temperature and/or annual average precipitation, (ii) soil properties, such as soil organic C content, soil texture, CEC and soil pH and (iii) agricultural management, such as N application rate per fertilizer type, type of crop and sometimes mode and timing of fertilizer application (see Bouwman et al. (2002b), (2002a) and Stehfest and Bouwman (2006)). The approach is, however, applied on a 0.5 x0.5 degree resolution, implying that many spatial differences are aggregated in average factors. When MITERRA would have used a similar approach, while including the more spatially disaggregated data, it would have allowed a systematic comparison of spatial aggregation on model results, without impacts of the model structure.

In the year 2000, the estimated total NH_3 emissions by INITIATOR2 are approximately 20% higher than the estimate by MITERRA, while the estimates for both N_2O and NO_x are 40% higher. The reason for the difference in NH_3 is not so much the description of the process, nor the used NH_3 emission fractions, but to a different assignment of the N inputs to grassland and arable land, showing the importance of a detailed manure application model. INITIATOR2 uses more detailed data within the Netherlands, i.e. at STONE plot level and even at farm level in case of animal numbers, as compared to MITERRA that uses NUTS2 level data. For N_2O and NO_x emission, also the model description is strongly different in INITIATOR2 as compared to MITERRA. In INITIATOR2, those fluxes are calculated as a fraction of the nitrification and denitrification fluxes, which in turn depend on factors such as soil type, ground water level and land use, whereas MITERRA uses constant fractions of the N input. Apparently, the INITIATOR2 approach lead to an overall higher N_2O and NO_x emission fraction, which is for N_2O in line with measurements in the Netherland (De Vries et al., 2005a).

The comparability of MITERRA and IMAGE results for Europe may be viewed as an indication that the model approach does not lead to a systematic under estimate or over estimate of those models on the European scale. The fact that results of NH_3, N_2O en NO_x emission for the Netherlands level by MITERRA deviate 20-40% from those derived by INITIATOR2 are then most likely an indication of the uncertainty of such levels at a national scale. However, comparison with other model approaches, and specifically independent data sets is needed to ascertain this statement.

5.2 Impacts of spatial aggregation on risks of ammonia emissions and nitrogen leaching in view of eutrophication

The comparative analysis discussed in this report showed that spatial aggregation of input data may lead to significant differences in the area exceeding critical loads in view of impacts on biodiversity, caused by N deposition, being largely influenced by the spatial variability in NH_3 emissions, and in ground water quality due to elevated NO_3 leaching. Even though a comparable methodological approach was used and country results were quite comparable for INITIATOR2 and MITERRA, the area exceeding critical N leaching rates in view of ground water critical limit of 50 mg NO_3/l differed strongly. In this study, the impact on the area exceeding critical N loads was much less at country level although the variation was large within the country (not shown).

In summary, results imply that spatial aggregation has a limited effect on most national and continental scale N inputs and most emission estimates but a large effect on the exceedance of critical N loads. Largest uncertainties are in the emissions of NO_x and N leaching and runoff, both at the national and European scale. Differences in model results are mainly due to differences in the use of basic data such as animal numbers and crop yields and in excretion, emission, uptake and leaching factors, and to a lesser extent related to differences in model structure.

Literature

Alcamo, J., R. Leemans & E. Kreileman (Eds.), 1998. *Global Change Scenarios of the 21st Century: Results from the IMAGE 2.1 Model.* Oxford, Elsevier Science.

Alcamo, J., (Ed.), 1994. *IMAGE 2.0. Integrated modeling of global climate change.* Water Air Soil Pollut. 76 (1-2), 1-318.

Bouwman, A.F., D.S. Lee, W.A.H. Asman, F.J. Dentener, K.W. van der Hoek & J.G.J. Olivier, 1997. *A global high-resolution emission inventory for ammonia.* Glob. Biogeochem. Cycles 11 (4), 561-587.

Bouwman, A.F., L.J.M. Boumans & N.H. Batjes, 2002a. *Modeling global annual N_2O and NO emissions from fertilized fields.* Glob. Biogeochem. Cycles 16 (4), 1080-1090.

Bouwman, A.F., L.J.M. Boumans & N.H. Batjes, 2002b. *Estimation of global NH_3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands.* Glob. Biogeochem. Cycles 16 (2), 1024.

Bouwman, A.F., K.W. van der Hoek, B. Eickhout & I. Soenario, 2005a. *Exploring changes in world ruminant production systems.* Agricultural Systems 84 (2), 121-153.

Bouwman, A.F., G. Van Drecht & K.W. Van der Hoek, 2005b. *Surface N balances and reactive N loss to the environment from intensive agricultural production systems for the period 1970-2030.* In Science in China Ser. C. Life Sciences, Vol. 48 Supp., pp. 1-13.

Bruinsma, J.A.M., 2003. *World agriculture: towards 2015/2030: An FAO perspective.* London, Earthscan Publications Ltd.

CPB, 1999. *WorldScan: the core version.* The Hague, CPB Netherlands Bureau for Economic Policy Analysis.

De Vries, B.J.M., D.P. van Vuuren, M.G.J.d. Elzen & M.A. Janssen, 2001a. *The Targets IMage Energy Regional (TIMER) Model. Technical Documentation.* Bilthoven, RIVM. RIVM report 461502024.

De Vries, W., J. Kros & O. Oenema, 2001b. *Modeled impacts of farming practices and structural agricultural changes on nitrogen fluxes in the Netherlands.* The Scientific World 1 (12-S2), 664-672.

De Vries, W., J. Kros, O. Oenema & J.W. Erisman, 2001c. *Assessment of nitrogen ceilings for Dutch agricultural soils to avoid adverse environmental impacts.* The Scientific World 1 (12-S2), 898-907.

De Vries, W., J. Kros, O. Oenema & J. de Klein, 2003. *Uncertainties in the fate of nitrogen II: A quantitative assessment of the uncertainties in major nitrogen fluxes in the Netherlands.* Nutr. Cycl. Agroecosyst. 66 (1), 71-102.

De Vries, W., J. Kros, P.J. Kuikman, G.L. Velthof, J.C.H. Voogd, H.J.J. Wieggers, K. Butterbach-Bahl, H.A.C. Denier Van Der Gon & A.R. van Amstel, 2005a. *Use of measurements and models to improve the national IPCC based assessments of soil emissions of nitrous oxide.* Environmental Sciences 2 (2-3), 217-233.

De Vries, W., J. Kros & G. Velthof, 2005b. *Integrated evaluation of agricultural management on environmental quality with a decision support system.* In: Zhu, Z., K. Minami & G. Xing (Eds). 3rd International Nitrogen Conference, October 12-16, 2004. Nanjing. China, Science Press, pp. 859-870.

Eickhout, B., M.G.J. den Elzen & G.J.J. Kreileman, 2004. *The Atmosphere-Ocean System of IMAGE 2.2. A global model approach for atmospheric concentrations, and climate and sea level projections.* Bilthoven, the Netherlands, National Institute for Public Health and the Environment. RIVM Report no. 481508017.

FAO, 1978-1981. *Reports of the Agro-Ecological Zones Project.* World Soil Resources Project No. 48, Rome, Food and Agriculture Organization of the United Nations.

FAO, 2007. *FAOSTAT database collections (http://www.apps.fao.org).* Rome, Food and Agriculture Organization of the United Nations.

Heckelei, T. & W. Britz., 2001. *Concept and explorative application of an EU-wide, regional agricultural sector model (CAPRI-Project).* Heckelei, T., H.P. Witzke & W. Henrichsmeyer (Eds). Agricultural sector modeling and policy information systems. Proceedings of the 65th European Seminar of the European Association of Agricultural Economists (EAAE), Wissenschaftsverlag Vauk Kiel KG, Kiel, Germany, Bonn, March 2000.

Hertel, T., 1997. *Global Trade Analysis: Modeling and Applications.* Cambridge University Press.

Hilderink, H.B.M., 2001. *World population in transition: an integrated regional modelling framework.* Amsterdam, Rozenberg.

Höglund-Isaksson, L. & R. Mechler, 2005. *The GAINS Model for Greenhouse Gases - Version 1.0: Methane (CH4). International Institute for Applied Systems Analysis.* Interim Report IR-05-54.

Image-team, 2001. *The IMAGE 2.2 implementation of the SRES scenarios: a comprehensive analysis of emissions, climate change and impacts in the 21st century.*

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H. Simon, Buendia, Leandro, Miwa, Kyoko, Ngara, Todd, Tanabe, Kiyoto (eds.).* IGES, Japan.

Klimont, Z. & C. Brink, 2004. *Modelling of emissions of air pollutants and greenhouse gases from agricultural sources in Europe.* International Institute for Applied Systems Analysis. Interim Report IR-04-048.

Leemans, R., E. Kreileman, G. Zuidema, J. Alcamo, M. Berk, G.J. van den Born, M. den Elzen, R. Hootsmans, M. Janssen, M. Schaeffer, S. Toet & B. de Vries, 1998. *The IMAGE User Support System: Global Change Scenarios from IMAGE 2.1.* Bilthoven, National Institute for Public Health and the Environment. CD-ROM publication 4815006.

Leemans, R., B. Eickhout, B. Strengers, L. Bouwman & M. Schaeffer, 2002. *The consequences of uncertainties in land use, climate and vegetation responses on the terrestrial carbon.* Science in China, Series C Life Sciences 45 (Supp.), 126-142.

Leip, A., G. Marchi, R. Koeble, M. Kempen, W. Britz & C. Li, 2008. *Linking an economic model for European agriculture with a mechanistic model to estimate nitrogen and carbon losses from arable soils in Europe.* Biogeosciences 5 (1), 73-94.

Li, C., 2000. *Modeling trace gas emissions from agricultural ecosystems.* Nutr. Cycl. Agroecosyst. 58, 259-276.

Li, C., J. Aber, F. Stange, K. Butterbach-Bahl & H. Papen, 2000. *A process oriented model of N2O and NO emissions from forest soils: I. Model development.* J. Geophys. Res. 105 (D4), 4369-4384.

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

MNP, 2006. *Integrated modelling of global environmental change. An overview of IMAGE 2.4.* Bilthoven, The Netherlands, Netherlands Environmental Assessment Agency (MNP).

Rotmans, J., 1990. *IMAGE. An integrated model to assess the greenhouse effect.* Dordrecht, Kluwer Academic Publishers.

Simpson, D., H. Fagerli, J.E. Jonson, S. Tsyro, P. Wind & J.-P. Tuovinen, 2003. *Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe PART I. Unified EMEP Model Description.* Norwegian Meteorological Institute. EMEP Status Report 2003.

Skiba, U., D. Fowler & K.A. Smith, 1997. *Nitric oxide emissions from agricultural soils in temperate and tropical climates: Sources, controls and mitigation options.* Nutr. Cycl. Agroecosyst. 48 (1-2), 75-90.

Stehfest, E. & L. Bouwman, 2006. *N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions*. Nutr. Cycl. Agroecosyst. 74 (3), 207-228.

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*. J. Environ. Qual. 35 (4), 1213-1226.

Van Aardenne, J.A., 2002. *Uncertainties in emission inventories*. PhD thesis, Wageningen, Wageningen University.

Van Dobben, H.F. & A. van Hinsberg, 2008. *Overzicht van kritische depositiewaarden voor stikstof, toegepast op habitattypen en Natura 2000 gebieden*. Wageningen, Alterra. Alterra rapport 1654.

Velthof, G., D. Oudendag & O. Oenema, 2007. *Development and application of the integrated nitrogen model MITERRA-EUROPE. Task 1 Service contract "Integrated measures in agriculture to reduce ammonia emissions"*. Wageningen, The Netherlands, Alterra. Alterra report 1663.1.

Velthof, G.L. & P.J. Kuikman, 2000. *Beperking van lachgasemissie uit gewasresten: een systeemanalyse*. Wageningen, Alterra. Rapport 114-3.

Velthof, G.L., D.A. Oudendag, H.P. Witzke, W.A.H. Asman, Z. Klimont & O. Oenema, 2009. *Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-EUROPE*. J. Environ. Qual. 38, 1-16.

Winiwarter, W., 2005. *The GAINS Model for Greenhouse Gases -Version 1.0: Nitrous Oxide (N_2O)*. International Institute for Applied Systems Analysis. IIASA Interim Report IR-05-55.

Appendix 1 The IMAGE/GTAP model

The IMAGE model

The Integrated Model to Assess the Global Environment (IMAGE) has initially been developed as an integrated assessment model to study anthropocentric climate change (Rotmans, 1990). Later it was extended to include a more comprehensive coverage of global change issues in an environmental perspective (Alcamo, 1994; Image-team, 2001). The current main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system.

IMAGE provides a dynamic and long-term assessment of the systemic consequences of global change up to 2100. The model was set up to give insight into causes and consequences of global change up to 2100 as a quantitative basis for analyzing the relative effectiveness of various policy options for addressing global change. Figure A1.1 provides an overview of the IMAGE modelling framework used in this analysis.

In earlier studies two models associated with, but not integrated in IMAGE, were used to provide basic drivers for the IMAGE model. These are the general equilibrium economy model, WorldScan (CPB, 1999), and the population model, PHOENIX (Hilderink, 2001). The WorldScan model provides input for IMAGE on economic developments, and PHOENIX provides input on demographic developments for both IMAGE and WorldScan. For the OECD Environment Outlook, the population projection is taken from the UN directly and is one of the inputs for the OECD ENV-Linkages model. The economic results from the ENV-linkages model are used as drivers to produce the detailed, physically oriented projections for the energy and land-use sectors by the IMAGE framework. Agricultural demand, production and trade is calculated by the GTAP model (see next section)

The various models in the IMAGE framework are:

- The TIMER model (see De Vries et al., 2001a) calculates regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies. On the basis of energy use and industrial production, emissions of greenhouse gases (GHG), ozone precursors and acidifying compounds are computed.
- The Terrestrial Environment System (TES) computes land-use changes based on regional production of food, animal feed, fodder, grass and timber, with consideration of local climatic and terrain properties, and changes in natural vegetation due to climate change. Consequently, emissions from land use changes, natural ecosystems and agricultural production systems, and the exchange of CO_2 between terrestrial ecosystems and the atmosphere are calculated,
- The Atmospheric Ocean System (AOS) calculates changes in atmospheric composition using the emissions from the TIMER model and TES, and by taking oceanic CO2 uptake and atmospheric chemistry into consideration.

Subsequently, AOS computes changes in climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport (see Eickhout et al., 2004).

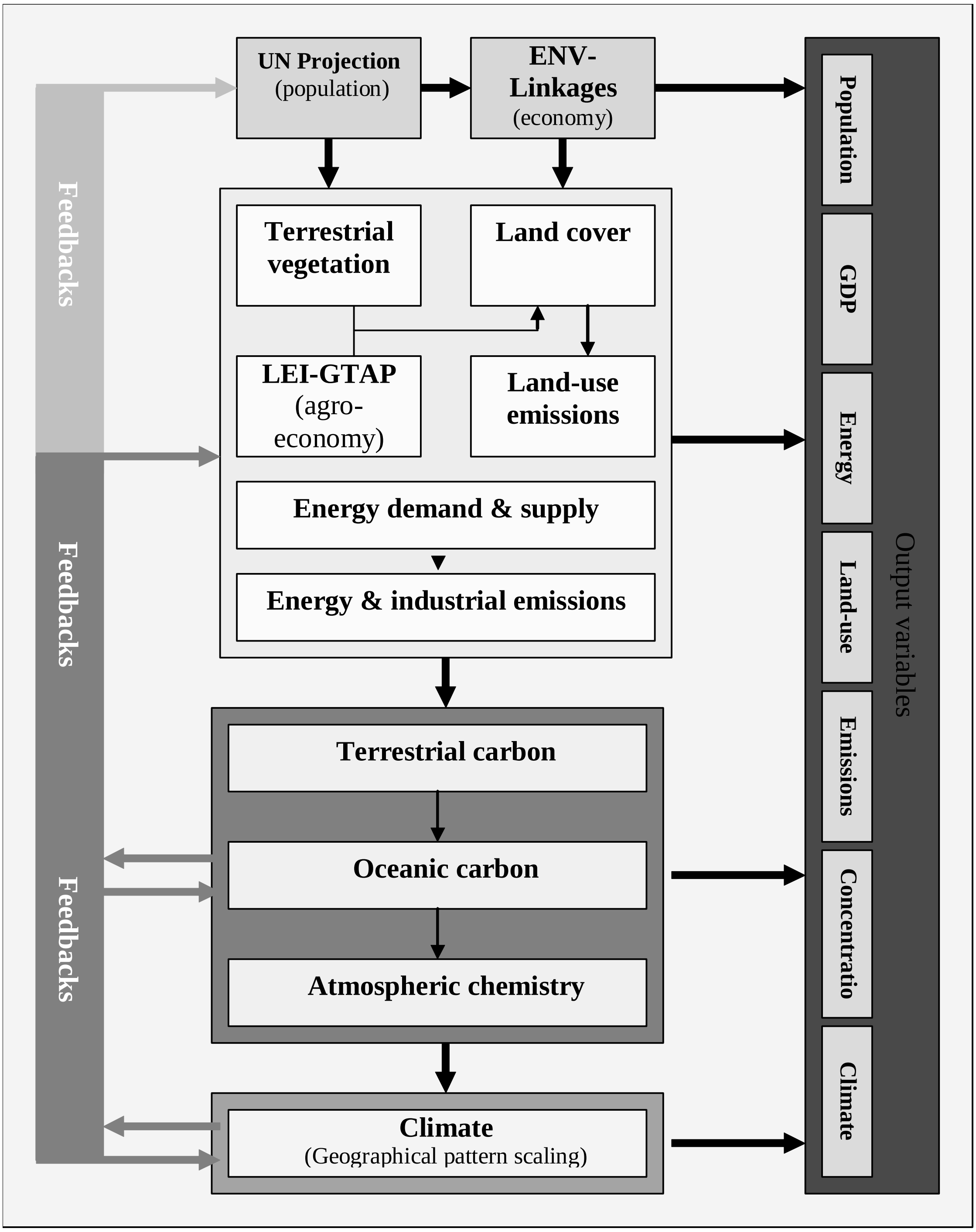

Figure A1.1 *Flow diagram of the IMAGE framework*

In this description we focus on the Terrestrial Environment System TES and it's sub-systems. The Terrestrial Vegetation Model (TVM) simulates the potential distribution of natural vegetation and crops on the basis of climate conditions and soil characteristics on a spatial resolution of 0.5 degree latitude by 0.5 degree longitude. It also estimates potential crop productivity, which is used by Land Cover Model (LCM), to determine the allocation of the cropland to different crops. First, TVM calculates 'constraint-free rain fed crop yields' accounting for local climate and light attenuation by the canopy of the crop considered (FAO, 1978-1981). The climate-related crop yields are adjusted for grid-specific conditions by a soil factor with values ranging from 0.1 to 1.0. This soil factor takes into account three soil quality indicators: (1) nutrient retention and availability; (2) level of salinity, alkalinity and toxicity; and, (3) rooting conditions for plants. The adjustment factor is calibrated using historical productivity figures and also includes the fertilization effect of changes in the atmospheric concentration of CO2. The CO2 fertilization is determined by the Terrestrial Carbon Model (TCM) that distinguishes different parameter settings per land cover type (Leemans et al., 2002). The resulting crop productivity, called 'reduced potential productivity of crops', is used in the land cover model.

The objective of the Land Cover Model (LCM) is to simulate global land use and land cover changes by reconciling the land use demand with the land potential. The basic idea of LCM is to allocate crop production on grid cells within a world regions until the total demand for this region is satisfied. The results depend on changes in the demand for food and feed as computed by GTAP. The allocation of land use types is done at grid cell level on the basis of specific land allocation rules like crop productivity, distance to existing agricultural land, distance to water bodies and a random factor (Alcamo et al., 1998).

IMAGE uses the historical data for the 1765-1970 period to initialize the carbon cycle and climate system. Actual simulations cover the period 1970-2050. Data for 1970-2000 are used to calibrate the IMAGE model against FAO data. For the period 2001-2050 the simulations are driven by the input from the TIMER model and GTAP, and by additional scenario assumptions on e.g. technology development, yield improvements and efficiencies of animal production systems.

The GTAP model

Standard GTAP model

The agro-economic analysis was done with an extended version of the general equilibrium model of GTAP (Hertel, 1997). In the GTAP model, a representative producer for each sector of a country or region makes production decisions to maximize a profit function by choosing inputs of labour, capital, and intermediates to produce a single sectoral output. Perfect competition is assumed in all sectors. In the case of crop and livestock production, farmers also make decisions on land allocation. Intermediate inputs are produced domestically or imported, while primary factors cannot move across regions. Markets are typically assumed to be competitive. When making production decisions, farmers and firms treat prices for output and input as given. Primary production factors land, labour and capital are fully employed within each economy, and hence returns to land and capital are endogenously determined at the equilibrium, i.e., the aggregate supply of each factor equals its demand. Each region is equipped with one regional household which distributes income across savings and consumption expenditures according to a fixed budget share.

Coupling of GTAP and IMAGE
Figure A1.5 shows the methodology of iterating the extended version of GTAP with IMAGE. The output of GTAP is, among others, sectoral production growth rates, land use, and a yield factor describing the change in land productivity because of technology improvements and the degree of land intensification. The degree of intensification is modelled endogenously by GTAP, while the technology improvement is assumed exogenously using information from FAO's study "World Agriculture towards 2015/2030" (Bruinsma, 2003).

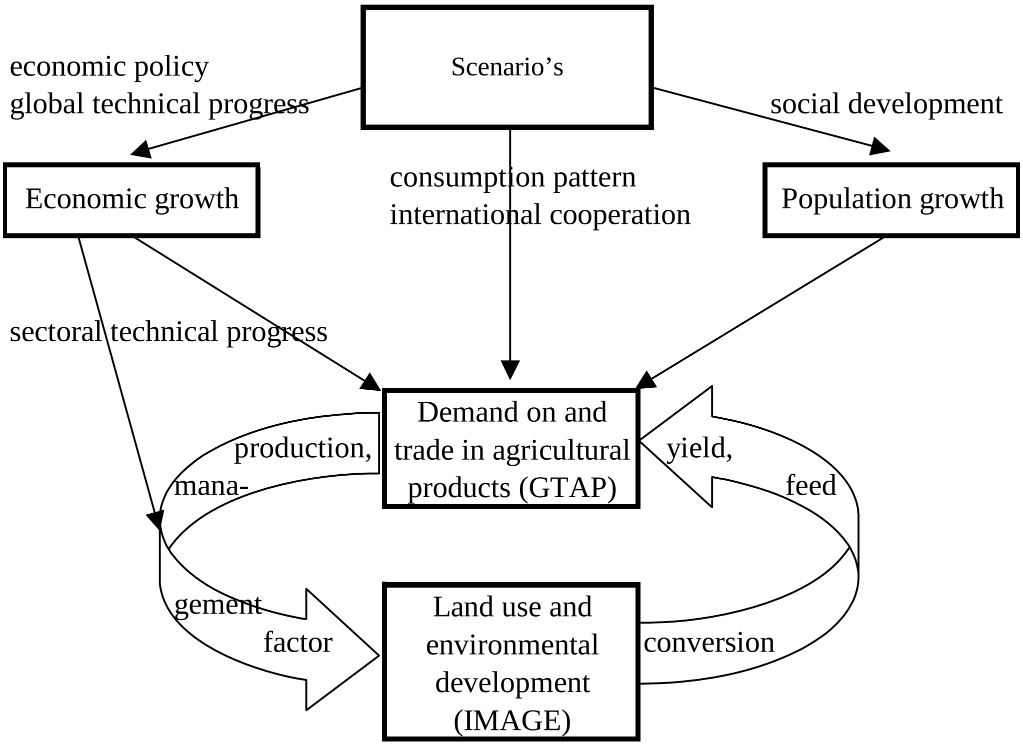

Figure A1.5 The modeling framework of GTAP and IMAGE

The output from GTAP is used by the IMAGE model to calculate change in crop productivity, the demand for land, feed efficiency rates and environmental indicators. This procedure delivers adjustments to the achieved changes in yields and changes in feed conversion, which are given back to GTAP. Through this procedure comparable land foresights are simulated in both models.

Appendix 2 The MITERRA model

Introduction

The MITERRA-Europe model was developed during the Service Contract "Integrated measures in agriculture to reduce ammonia emissions" funded by DG Environment. The general objective of the service contract was to define the most appropriate integrated and consistent actions to reduce various environmental impacts of nitrogen from agriculture, notably the effects on quality of water and air and on greenhouse gas emissions1. The MITERRA-Europe model 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 ammonia, nitrous oxide (N_2O), N oxides (NO_x), and methane (CH_4) to the atmosphere, leaching of N (including nitrate) to ground water and surface waters, and on the phosphorus (P) balance at EU-27 level, country level, and regional (NUTS-2) level (Velthof et al., 2007; Velthof et al., 2009).

MITERRA-Europe is based on the existing models RAINS/GAINS (Regional Air Pollution Information and Simulation; http://www.iiasa.ac.at/rains) and CAPRI (Common Agricultural Policy Regionalized Impact; http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm), supplemented with a N cycle and leaching module, data bases (from e.g. FAO, Eurostat and JRC), soil data, literature and expert knowledge. MITERRA-Europe is a deterministic and static N cycling model which calculates N emissions on an annual basis, using N emission factors and N leaching fractions. MITERRA-Europe consists of an input module with activity data and emission factors, a module with measures to mitigate NH_3 emission and measures to mitigate NO_3 leaching, a calculation module, and an output module.

RAINS/GAINS estimate current and future gaseous N and C emissions from agriculture (and other sectors) in Europe. It incorporates databases on economic activities, e.g. forecast of agricultural activities and number of livestock. Emission factors and removal efficiencies used in RAINS/GAINS are derived from various studies (Klimont & Brink, 2004). CAPRI is an agricultural sector model on a regional level in EU 27, with a global market model for agricultural products (Heckelei & Britz, 2001). Agricultural supply is derived from 38 crops and 19 animal activities covering most agricultural activities, and feed and further input demand are modelled in detail. Major results of the system include yields, cropped areas, number of animals, output quantities, and emissions to the environment and the economic consequences of environmental and economic policies.

Modeling approach

MITERRA-EUROPE is a model consisting of an input module with activity data and emission factors, a set of (packages of) mitigation measures, a calculation module, and an output module In Figure A2.1 a schematic overview of MITERRA-EUROPE is presented. All arrows in the figure are calculated within MITERRA-Europe.

[1] More information about the project can be found on: http://www.scammonia.wur.nl

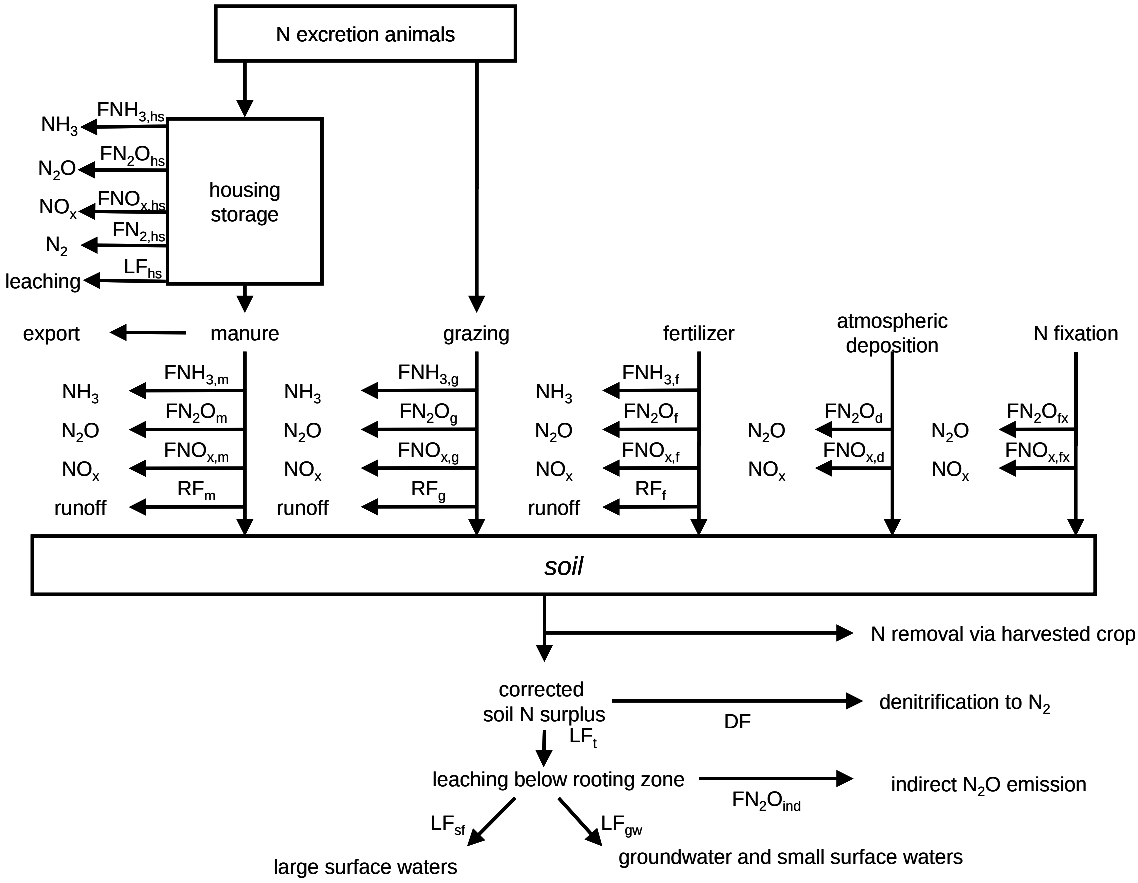

Figure A2.1. Schematic overview of MITERRA-Europe. F indicates emission factor for gaseous emissions, L leaching fraction, D denitrification fraction, and R runoff fraction.

The data used in MITERRA-Europe is on regional (NUTS-2) level or country level and includes data of N inputs, N outputs, land use, crop types, soil type, topography, livestock numbers, emission factors for NH_3, N_2O, NO_x and CH_4, and leaching factors for N.

The total N excretion is calculated as the number of animal times the excretion per animal, for the different types of animals. The animal categories and number of animals from RAINS scenarios are used and the distribution of animals to NUTS-2 regions is based on the regional distribution of animals in CAPRI. N excreted during grazing is calculated using information about the number of grazing days (grazing). The other part of excreted N is from housed animals and is stored in a manure storage and subject to emissions. The gaseous N losses (NH_3, N_2, N_2O, NO_x) from animal manure during housing and storage are calculated using emission factors. The emission factors are obtained from the RAINS/GAINS model (Klimont & Brink, 2004) and are country specific.

The N input to soils consists of manure, fertilizer, biological N fixation and atmospheric deposition. 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/or grazing 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 area of crops per NUTS 2 regions are obtained from CAPRI, while yields of arable crops were obtained from FAO statistics. The distribution of manure over crops is based on Menzi (2002) and expert knowledge.

The national fertilizer consumption rates are obtained from FAO. The mineral fertilizer is distributed over crops at country level using weighing factors, based on the calculated crop N demand and the crop area. The N contents of crop products and the amount of crop residues were based on a literature review of Velthof and Kuikman (2000) for the Netherlands. Since N content of crops and crop residues are related to the N input, the N contents were adjusted using a plant-available N dependent factor.

Biological N fixation for arable soils was set at 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 was set to the amount of N in the harvested products. The atmospheric N deposition is obtained 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 (for 50%) proportionally adjusted to changes in NH_3 emission. All above mentioned N inputs are subject to emission losses, which are calculated with emission factors. For N_2O and CH_4 emissions the default IPCC method is used, for NH_3 the country specific emission factors from RAINS/GAINS model (Klimont & Brink, 2004) are used and for NO_x the emission factor is derived from the review paper of Skiba et al. (1997).

MITERRA-Europe considers leaching from stored manure, runoff on agricultural soils, and leaching below the rooting depth, which can be divided in leaching to larger surface waters via subsurface flow and leaching to deep groundwater and small surface waters. The leaching fractions were calculated based on crop, soil and climate data using the Homogenous Spatial Mapping Units (HSMUs) developed in the CAPRI-Dynaspat project. The NO_3 concentration in soil water is calculated from N leaching 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. The water flux is calculated according to Tiktak et al. (2006) and is based on data on precipitation and transpiration of cropped soils.

Measures

For MITERRA-Europe the reference year is 2000 and measures that are implemented start from the situation in 2000. The following ammonia abatement measures of RAINS are included in MITERRA-Europe:

- Low N Fodder (dietary changes)
- Stable Adaptation
- Covered Manure Storage (low efficiency and high efficiency options)
- Biofiltration (air purification);
- Low Ammonia Application of manure (high efficiency and low efficiency techniques)
- Urea substitution (substitution of urea with ammonium nitrate)
- Incineration of poultry manure

To decrease N leaching and to accomplish to the constraints of the Nitrates Directive the following (package of) measures are available 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

Finally for the implementation of the Water Framework Directive (WFD) the following measures were included:

- 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 P leaching to surface water

Appendix 3 The INITIATOR2 model

To gain insight in all environmental impacts of excessive manure application simultaneously, an integrated model INITIATOR2 (Integrated Nutrient ImpacT Assessment Tool On a Regional scale) was developed (De Vries et al., 2005b). INITIATOR2 is an extension of the model INITIATOR (Integrated NITrogen Impact Assessment Tool On a Regional scale) that was developed to: (i) gain insight in the fate of all major nitrogen flows in the Netherlands (De Vries et al., 2003), (ii) calculate 'regional specific nitrogen ceilings' (maximum amounts of reactive nitrogen that does not lead to exceedance of critical limits or targets) (De Vries et al., 2001c) and (iii) assess the impacts of improved farming practices and technical measures such as changes in animal housing on nitrogen fluxes in the Netherlands (De Vries et al., 2001b). Apart from all N fluxes, INITIATOR2 also includes the emissions of carbon dioxide, methane, fine particles and odour and the accumulation, runoff and leaching of phosphate, base cations and heavy metals (De Vries et al., 2005b).The policy aim of INITIATOR2 is to provide information on the effectiveness of specific (single target oriented) policies on the simultaneous reduction of relevant element fluxes (green house gases, nutrients and heavy metals) to atmosphere, ground water and surface water

This annex presents the features of this integrated model system and a demonstration how the model can be used for the evaluation of mitigation measures and policies on greenhouse gas emissions. Measures and policies included are either directly aimed at the emission reduction of non-CO_2 greenhouse gases or aimed at a reduction of NH_3 emissions and N leaching. Considered mitigation measures include improved farming practices, such as a change in drainage status, and structural changes in agriculture. We report on gaseous emissions and likely interactions and trade - offs between various policies.

Modeling approach: A flow chart of the considered element inputs and element transformation processes in the model INITIATOR2 is given in Figure A3.1. The flow chart is limited to the agricultural part of the model. A so-called CBS/GIAB database contains animal numbers for each farm in the Netherlands. The NH_3, NO_x, N_2O, CH_4 and odour emissions from housing and manure storage systems are described by a multiplication with excretion factor and/or emission factor for different animal categories, depending on the type of emission (a maximum of 65 categories in case of N excretion and NH_3 emission). Results of the N, P and metal excretion are input for a simple manure transport model predicting manure export from intensive animal husbandry areas and manure import in less intensive areas. This module also calculates the related fertilizer use. NH_3 emissions due to N input by manure application and grazing are calculated in the soil model (the core) of INITIATOR2. Together with NH_3 emissions from housing systems, it forms the input of a simple atmospheric transport model (a transfer matrix based on results of the detailed OPS model). The INITIATOR2 soil model also calculates the emissions of CH_4, CO_2 and N_2O from terrestrial systems and the accumulation, leaching and runoff of carbon, nutrients (nitrogen, phosphate and base cations) and metals to ground water and surface water.

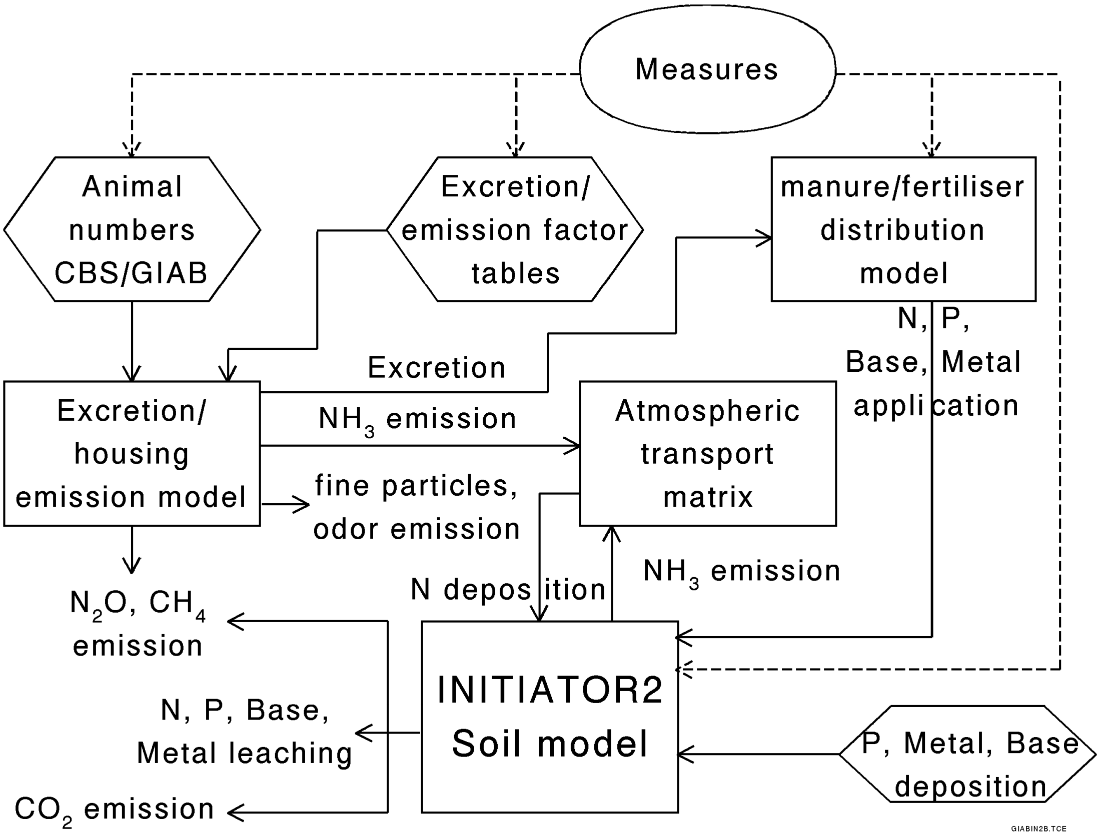

Figure A3.1 Coupling of modules and model outputs in the INITIATOR2 model for agriculture

The processes and fluxes treated in INITIATOR2 are (De Vries et al., 2005b):

- NH_3, NO_x and N_2O emission from housing and manure storage systems, soils and surface waters (NO_x and N_2O; focus of INITIATOR2)
- Fine particle and odour emissions from housing and manure storage systems
- Methane (CH_4) emission from housing and manure storage systems and terrestrial ecosystems.
- Atmospheric emission of the greenhouse gases CO_2 and CH_4 from housing systems (not for CO_2), terrestrial ecosystems (with a focus on peat soils).
- Uptake, soil accumulation/release (adsorption/desorption and mineralization/ immobilization), leaching and runoff of nitrate and ammonium (focus of INITIATOR2) phosphate, base cations (Ca, Mg, K) and heavy metals (Pb, Cd, Cu and Zn) to ground water and surface water.

Measures can affect both animal numbers (CBS/GIAB database), excretion factors or emission fractions (changes in table) or parameters in INITIATOR2 influencing the fate of element in soil, ground water and surface water (see Figure 1). Considering the focus of this paper, we limit our description to NH_3 fluxes and non CO_2 green house gas (nitrous oxide and methane) emissions.

NH_3 and N_2O housing emissions: In the most recent version of INITIATOR2, NH_3, NO_x and N_2O emissions from housing and manure storage systems are described by

a multiplication of: (i) an excretion factor [kg N/animal per year] for various animal categories with (ii) the number of animals in each category, based on geographically explicit system called GIAB with available data for each farm in the Netherlands, and (iii) an emission percentage (% NH_3, NO_x or N_2O compared to N excretion). More details on the used animal categories (a total of 65) are given in De Vries et al. (2005b).

NH_3 and N_2O soil emissions. The various N fluxes from and in agricultural soils are calculated with a consistent set of simple linear equations (De Vries et al., 2003). First the total N input to the soil is calculated as the sum of inputs by animal manure, fertilizer, atmospheric deposition and biological N fixation. The fate of N in soils is calculated as a sequence of occurrences in the order ammonia emission, followed by N uptake, N mineralization/ immobilization, nitrification and denitrification in the soil. All N transformation processes are a linearly function of the inflow of N, namely: (i) the N input to the soil ammonia emission to, (ii) the (effective) N input minus the NH_3 emission for N uptake (N removal from the field), (iii) the net N input (N input minus NH_3 emission minus N uptake) for N mineralization/ immobilization, (iv) the net N input minus N mineralization/immobilization for nitrification and the nitrification flux for denitrification.

The NH_3 emissions from soils are calculated by a multiplication of the N inputs by manure and fertilizer application and grazing cattle with specific N emission fractions for these inputs. Maximum N uptake rates (at sufficient N supply) are given as a function of land use (in our study grass, maize and arable land using a mixture of wheat, other cereals, potatoes, sugar beet and other crops), soil type (sand, loess, clay and peat) and ground water table (dry, moist and wet) in terms of a maximum yield and related N contents. The uptake and soil N transformation fractions are given as a function of land use, soil type and/or hydrological regime.

The N_2O emission from soils is calculated as the multiplication of specific N_2O emissions fractions with the nitrification flux and denitrification flux. In INITIATOR2, the N_2O emission due to oxidation of peat soils induced by net N mineralization in response to lowered ground water levels has been improved compared to the original INITIATOR version. Net N mineralization is calculated by multiplying the oxidation of organic carbon in the peat soil with an N/C ratio and a reduction function relating N mineralization to C mineralization. The oxidation of organic carbon in the peat soil is calculated by a multiplication of: (i) the annual lowering of the peat soil ($mm.yr^{-1}$), which is derived as a function of the mean lowest groundwater level with (ii) the bulk density of the peat, which in turn is a function of the organic matter content ($kg.m^{-3}$), and (iii) the fraction of organic carbon in the peat.

Methane emissions: The CH_4 emission from housing and manure storage systems is described quite comparable to NH_3 and N_2O emission. The emissions due to enteric fermentation in animals, occurring both in housing systems and in the field, is calculated by a multiplication of: (i) an emission factor [kg CH_4/animal per year] for various animal categories with (ii) the number of animals in each category, lumped in

11 main animal categories. The CH_4 emission from animal manure stored in housing and storage systems is calculated by a multiplication of: (i) an emission factor [kg CH_4 m^{-3} manure per year] for 7 animal manure categories with (ii) the manure volume. The latter amount was calculated by a multiplication of: (i) a manure excretion factor [kg /animal per year] for the distinguished 65 animal categories with (ii) the number of animals in each category and (iii) the reciprocal of the bulk density of the manure (m^3/kg). The CH_4 emission from terrestrial systems is set at a constant average value with the exception of natural grasslands that do emit CH_4 at a rate depending on the ground water level.