

European Nitrogen Assessment

Chapter 15: Geographical variation in terrestrial nitrogen budgets across Europe & Chapter 16: Integrating nitrogen fluxes at the European scale

Supplementary Material: Annex I - A description of used models and data sets and comparisons of model results

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15&16.A1. A description of used models

Complete N budget models

Complete N budget models are models that are able to calculate a land system budget, including the N emissions occurring in housing and manure management systems. Currently, this includes the models INTEGRATOR, IDEAg (CAPRI based model), MITERRA and IMAGE. A summary of abbreviations used is given in Annex 1.

INTEGRATOR/MITERRA

INTEGRATOR and MITERRA are models including complete N budgets, focusing at EU level (EU25-EU30). MITERRA (Velthof *et al.*, 2009), often denoted as 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. The model can be used to assess the effects of measures and policies on the emissions of ammonia, nitrous oxide (N₂O), N oxides (NO_x), and methane (CH₄) to the atmosphere, leaching of N (including nitrate) to ground water and surface waters, and on the phosphorus (P) budget at EU-27 level, country level, and regional (NUTS-2) level. While MITERRA focuses on agriculture only, INTEGRATOR (De Vries *et al.*, 2010a) (2010b), which includes an adapted version of MITERRA, also considers non-agricultural systems. N deposition is treated by an emission-deposition matrix for NH₃ and NO_x, accounting for the interaction between agricultural and non-agricultural soils and N₂O emissions from ground water and surface waters are considered. Furthermore INTEGRATOR calculates at the level of homogeneous combinations of

land use, soil type etc., whereas MITERRA calculates at regional level. For agricultural systems, an emission and leaching/runoff factor approach is used in both MITERRA and INTEGRATOR, with more detail in emission factors in the latter approach. For the non agricultural systems, an empirical model approach is used in INTEGRATOR, which relates the N₂O and NO_x emissions to spatially referenced N inputs and stand/site characteristics, including meteorological parameters and soil characteristics.

CAPRI

The CAPRI Common Agricultural Policy Regionalised Impact) model is a regionalized economic model for agriculture described in detail in Britz *et al.* (2005) and Britz & Witzke (2008). Within the CAPRI modelling system, a database has been established, which stores production statistics (crop acreages, animal population numbers etc) at the regional level. It is based as far as possible on official EU statistics obtained from EUROSTAT, but the data are checked on consistency and completeness and identified data gaps or data inconsistencies are gap filled or corrected, respectively. Three nitrogen budgets are consistently calculated in the CAPRI model: the market budget, the animal budget and the soil budget (see Leip *et al.*, 2009a). The market budget considers trade of agricultural commodities in Europe within a global market and European policy situation and their distribution over various uses (feed, human consumption, industrial processing etc.). The animal budget calculates inputs of nitrogen by feed (green fodder, feed concentrates etc.) and the output in animal products. Feed input is estimated on the basis of the protein requirements of the animals and the available protein content in feedstuff. The residual between N intake and N in products gives total N excretion. The link to the soil budget is achieved with the manure budget, which calculates Nr losses occurring before manure application on soil, whereby manure deposited by grazing animals is treated separately. These Nr losses as well as the loss-terms in the soil N-budget are calculated in a similar way as in the MITERRA model.

The IDEAg model system

The Indicator Database for European Agriculture (IDEAg, Leip *et al.*, 2009b) combines information from the economic model for agriculture CAPRI (Britz *et al.*, 2005; Britz & Witzke, 2008) with information derived from a process-based model for nitrogen turnover in agricultural soils, the DeNitrification DeComposition model (DNDC, Li *et al.*, 1992; Li, 2000), which had been adapted for the Europe-wide application (Leip *et al.*, 2008). In the IDEAg results from the “CAPRI/DNDC-EUROPE” modelling framework are stored, which consists of three elements; (i) the CAPRI-SPAT downscaling model (Leip *et al.*, 2008); (ii) the DNDC-CAPRI meta-model (Britz & Leip, 2009); and (iii) an interface combining results of the DNDC-CAPRI meta-model with elements of CAPRI-SPAT, yielding a database with environmental indicators that are inherently consistent and operating at the level of individual crops. The CAPRI-SPAT downscaling model provides the main agronomic input data required to run DNDC or the DNDC meta-model, i.e.: land use (acreage) and livestock density, yield for each crop, application rates of mineral fertilizer nitrogen and manure nitrogen, the amount of manure deposited on grassland during grazing, and the C/N ratio of applied manure. The downscaling procedure is described in detail in Leip *et al.* (2008). In addition, CAPRI-SPAT scales down the nitrogen budget and GHG and N-gas emissions (NH₃, NO_x, N₂) which have been calculated with the IPCC and MITERRA (Velthof *et al.*, 2008) approaches as implemented in

CAPRI (Britz & Witzke, 2008). As the spatial calculation unit, “Homogeneous Spatial Mapping Units” (HSMUs) are used which are defined by a Corine land cover class (Corine2000, European Topic Centre on Terrestrial Environment, 2000), a soil mapping unit (European Commission, 2004), slope on the basis of data from the Catchment Characterisation and Modelling DEM 250 (2004), and an administrative region at the so-called NUTS2-level (EUROSTAT, 2003). For Europe, a total of 206000 HSMUs are obtained. In IDEAg, the individual terms from the DNDC meta-model (N₂, N₂O, NO_x, N-leaching) are combined with terms from CAPRI-SPAT (other N-fluxes) and adjusted with a set of rules to obtain a closed N-soil budget.

IMAGE

The Integrated Model to Assess the Global Environment (IMAGE) is a dynamic integrated assessment modelling framework for global change (Alcamo, 1994; Leemans *et al.*, 1998; MNP, 2006). IMAGE provides: (i) dynamic and long-term perspectives on the systemic consequences of global change, (ii) insights into the impacts of global change and (iii) a quantitative basis for analyzing the relative effectiveness of various policy options to address global change. IMAGE 2.4 simulations cover the 1970-2100 period (end year dependent of scenario choice). Data for 1970-2000 are used to calibrate the model. Simulations up to the year 2100 are made on the basis of scenario assumptions on, for example, demography, food and energy consumption and technology and trade. IMAGE 2.4 is global in application and makes standard predictions for 24 world regions (energy, trade and emissions). In Europe, a distinction is made in OECD Europe and Eastern Europe. However, IMAGE performs many of its calculations also on a high-resolution terrestrial 0.5 by 0.5 degree grid (land use and land cover) and for Europe it includes country based calculations of N fluxes (NH₃ and N₂O emissions and N leaching/runoff). In the IMAGE 2.4 framework, general equilibrium economy is taken from different economic models dependent of the scenario that is applied. For NH₃ emissions, the IMAGE model also contains an empirical model, relating NH₃ emissions to environmental factors and management factors (Bouwman *et al.*, 2002; Stehfest & Bouwman, 2006). For calculating the N budgets in agricultural systems IMAGE uses a soil budget approach, similar to OECD (2008). Based on country data from primarily FAO (2008) the N inputs from animal manure, fertilizer use, biological N₂-fixation, atmospheric N deposition, and output of N in harvested products is estimated. Total manure production within pastoral and mixed and landless systems is computed from the animal stocks and N excretion rates from Van der Hoek (1998).

N emission models

Atmospheric N emission models are models that calculate Nr (NH₃, N₂O, NO_x) emissions from all relevant sources (agriculture, industry, traffic etc) based on N use data from all these activities. The most commonly used approaches for assessing Nr (NH₃, N₂O, NO_x) emissions for Europe are simple Activity-data (AD) x Emission factor (EF) approaches, such as described in the IPCC guidelines (e.g., IPCC, 2006). In integrated models such as GAINS or in the Emission Database for Global Atmospheric Research, EDGAR, (Van Aardenne, 2002), an extended approach has been applied, with consideration of mitigation techniques, according to:

$$E_{x,c,y} = \sum_{s,t,m} \{A_{c,s,y} \cdot f_{c,s,t,y} \cdot EF_{c,s,t,x,y} \cdot i_{c,s,t,m,y} \cdot (1 - R_{c,s,t,m,x})\}$$

where E is the emission level for gas x in country c in year y ; A is the activity level for emission source s in country c and year y ; f is the fraction of emission technology t with the corresponding emission factor EF for gas x ; i is the implementation level of an end-of-pipe emission reduction measure m with the corresponding reduction fraction R of the emission flux for gas x .

RAINS/GAINS

The Greenhouse gas, Air pollution INteractions and Synergies (Klaassen *et al.*, 2004; Klimont & Brink, 2004; Höglund-Isaksson & Mechler, 2005; Winiwarter, 2005) model GAINS has been developed at the International Institute for Applied Systems Analysis (IIASA) as a tool for the integrated assessment of emission control strategies for reducing the impacts of air pollution and greenhouse gas emissions. Originally limited to air pollution only (Alcamo *et al.*, 1990) it was known as the RAINS model. The present version of GAINS addresses health impacts of fine particulate matter and ozone, vegetation damage from ground-level ozone as well as acidification and eutrophication. To explore synergies between these environmental effects, GAINS includes emission controls for sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH₃) and fine particulate matter (PM) (Cofala *et al.*, 2000). The recent extension to greenhouse gases allows the analysis of co-benefits and tradeoffs between air pollution and climate policies. The GAINS emission modules at IIASA predict NO_x and NH₃ emissions (RAINS) and CO₂, CH₄ and N₂O emissions (GAINS) at a country level.

EDGAR

EDGAR (Emission Database for Global Atmospheric Research) (Van Aardenne *et al.*, 2009; available at: <http://edgar.jrc.ec.europa.eu>) is a global gridded emission inventory of air pollutants and greenhouse gases. The database contains emissions data of six groups of substances, i.e. all greenhouse gases, ozone precursor gases, acidifying gases, fine particulate matter, primary aerosols, and stratospheric depleting substances. In total, EDGARv4.0 estimates anthropogenic emissions from 25 substances, including the important Nr gases N₂O, NH₃ and NO_x. The anthropogenic emissions are estimated for the following main sectors: stationary combustion, transportation, fugitive emissions from fuel production, industrial processes and product use, agriculture, waste and other. In addition, emissions from forest, grassland and other vegetation fires are included, whether anthropogenic or not.

The emissions are modelled based on latest scientific knowledge, available global statistics, and methods recommended by the Intergovernmental Panel on Climate Change (IPCC). Official data submitted by the industrial Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Kyoto Protocol are used to some extent, especially regarding the control measures implemented since 1990 that are not available from international statistics. However, the emissions reported by countries are not used entirely because of the prerequisite of cross-country consistency and impartiality. Calculations are done at national level, but the emissions are further gridded to 0.1 x 0.1 degree by using various maps such as human and animal population density, croplands and grasslands, industrial point sources, road network, aviation and shipping routes.

EDGARv4.0 provides a reference historic emission dataset with the advantage of (a) explicit modelling of the changes of emission factors over time due to the changes in the mix of technologies; (b) explicit modelling of the emission control technologies with their reduction efficiencies; and (c) incorporation of the latest scientific knowledge by using the emission factors from IPCC (2006) or latest scientific literature. Furthermore, it is used in forward-looking studies investigating e.g. the potential synergy and co-benefit of climate and air pollution policies.

The Unified EMEP model

EMEP (European Monitoring and Evaluation Programme) is a scientifically based and policy driven programme under the UNECE (United Nations Economical Commission for Europe) Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems. According to the 2002 work-plan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/75, annex VI), Parties of the Convention are requested to report to the secretariat emission data on e.g. nitrogen oxides (NO_x) and ammonia (NH₃). UNECE/EMEP emission data is available for retrieval and review in the web version of the UNECE/EMEP emission database (available through www.emep.int).

The atmospheric emissions are used in the EMEP MSC-W Eulerian model, being an atmospheric chemical transport model, designed primarily for the calculation of acidifying substances, ozone and particles over Europe (Simpson *et al.*, 2003, see also www.emep.int and chapter 12). Traditionally, the model has been run with for a European domain with a horizontal resolution of 50 x 50 km², but results at 20x20 km² and even 10x10 km² have recently been presented (e.g. Fagerli *et al.*, 2009). Both global and local versions of the model have been developed (Jonson *et al.*, 2007; Vieno *et al.*, 2009). The chemical scheme uses about 140 reactions between 70 species (see Andersson-Sköld & Simpson, 1999 and refs therein), and makes use of the EQSAM module of Metzger *et al.* (2002) to describe equilibria between the inorganic aerosol components. Routine N-deposition fields from the EMEP model are available at www.emep.int. Calculations of forest-specific depositions, also exploring the role of forest soil-NO emissions from Kesik *et al.* (2005), were presented in Simpson *et al.* (2006).

The EMEP models have been instrumental to the development of air quality policies in Europe since the late seventies, mainly through their support to the strategy work under the Convention on Long-range Transboundary Air Pollution and became the reference atmospheric dispersion model for use in the Integrated Assessment Models supporting the development of air quality policies under the EU Commission.

UNFCCC/IPCC

Over a decade ago, most countries joined an international treaty -- the United Nations Framework Convention on Climate Change (UNFCCC) -- to begin to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. Parties to the Convention must submit national reports on implementation of the Convention to the Conference of the Parties (COP). The core elements of the national communications for both Annex I and non-Annex I Parties are information on emissions and removals of greenhouse gases (GHGs) and details of the activities a Party has undertaken to implement the Convention. Annex I Parties

are required to submit information on their national inventories annually, and to submit national communications periodically, according to dates set by the COP. An entry to the UNFCCC GHG data interface which provides access to the most recent GHG data reported by countries that are Parties to the Climate Change Convention is given on the internet (http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php).

N loss models

N loss models are models that focus on the calculation of the N loss from the soil to aquatic systems by assessing the main N fluxes in the soil system (inputs, removal, etc) and the routing of the excess input to ground water and/or surface water. Unlike complete N budget models they can not calculate a land system budget, since N emissions from housing and manure management systems are not included, and soil emissions are often only implicitly accounted for.

GREEN

The GREEN (Geospatial Regression Equation for European Nutrient losses) model (Grizzetti *et al.*, 2005; Grizzetti *et al.*, 2008; Bouraoui *et al.*, 2009) distinguishes between the terrestrial basin, receiving non-point sources of nitrogen and the drainage network receiving diffuse inputs from the watershed as well as point inputs from urban and industrial sources and upstream basins. This approach allows differentiating between 'in-stream' and 'landscape' (or 'terrestrial') retention processes. The model expresses the annual riverine nitrogen export at the outlet of a catchment as a function of point sources affected by river retention only and diffuse sources due to soil inputs (atmospheric deposition, mineral fertilizer, manure and crop N fixation), affected by both landscape and in-stream retention. Crop uptake is part of the landscape retention processes. In-stream retention is exponentially related to residence time in the drainage network and landscape retention is inversely related to precipitation. The parameters of these relationships are calibrated by statistical procedures.

EPIC-EAGLE

The EPIC-EAGLE model is a specific ESRI ArcGis geodatabase environment structuring all the relevant geographic information to perform modelling with EPIC (Williams, 1995), at a European scale (Bouraoui & Aloe, 2007). The EPIC (Environmental Policy Integrated Climate) model is a continuous simulation model that can be used to determine the effects of management strategies on agricultural production on soil and water quality. EPIC-EAGLE has amongst others been used to model pan-European rapeseed cultivation and environmental efficiencies (Van der Velde *et al.*, 2009) and estimations of pan-European irrigation requirements (Wriedt *et al.*, 2009). EPIC is also being used for studies on climate change impact on European agriculture with special reference to nutrient cycling, and has been tuned against regional NUTS2 crop yields for the period between 1995-2003 across Europe for 9 of Europe's main crops (soft wheat, barley, rye, sunflower, durum wheat, rapeseed, rice, maize and cotton, unpublished data). The EPIC implementation is run with a daily time step on 10 by 10 km grid cells covering the EU-27 plus Switzerland.

15&16.A2. Data sets to estimate N inputs, N uptake and N emissions

In this section, we describe the data sets that were used to estimate N inputs and N uptake by INTEGRATOR IDEAg (and CAPRI), MITERRA and IMAGE.

Land cover and land use

Source of land use data by the various models are:

- **INTEGRATOR** uses the CLUE model outcome with respect to land cover, which is based on CORINE with respect to the year 2000. The fraction of crops in arable land is based on the agricultural land use map obtained from the CAPRI-DNDC disaggregation model.
- **IDEAg (CAPRI)** uses information on land use from EUROSTAT production statistics. In the CAPRI-DNDC disaggregation model, the information at regional level are downscaled and made available to other EU models (see above). The most important additional dataset used is the LUCAS database (EC, 2003), which stands for Land Use/Cover Area Frame Statistical Survey. This database contains ca. 100000 ground-truth observations and has been used to calibrate individual regression (logit) models for each land use, land cover class and region around the year 2000. In the CAPRI-DNDC disaggregation model, estimates of the regression model are used as *a priori* information to obtain a land use distribution consistent with the current CAPRI simulation.
- **MITERRA** bases the area of both grassland and arable land (plus that of all crops) on CAPRI. The area of rough grazing is a fraction of the total grassland area of CAPRI, derived from EUROSTAT.
- **IMAGE** estimates the area of arable land as the production per country divided by crop yields and multiplied by the cropping intensity, which is defined as harvested area divided by arable area, to correct for fallow land. The data on agricultural production, crop yields and cropping intensity for the period 1970-2000 are all based on the FAO database at country level (FAO, 2001).

A comparison of results for the various models with respect to land areas used is given in Table 15&16.A1.

Table 15&16.A1 Land areas used in INTEGRATOR, IDEAg, MITERRA and IMAGE for EU 27 in 2000.

Land use	Area (Mha)			
	INTEGRATOR	IDEAg	MITERRA	IMAGE
Grass land ¹	56.4	64.3	64.0	68.2
Permanent crops	14.5	12.0	12.1	
Annual crops	122.4	99.5	99.9	131.7 ²
Other ³	-	9.7	9.0	-
Total agricultural land	193.4	185.1	185.0	199.9

¹ Grass land in INTEGRATOR only includes intensively and extensively managed grass land. In IDEAg and MITERRA it also includes rough grazing areas. In MITERRA, this area is estimated at 19.4 Mha

² This includes the sum of permanent crops and annual crops (total arable land), since IMAGE does not make a distinction between these type of crops.

³ Other in IDEAg includes voluntary set-aside, fallow land and bio fuel crop production (mainly rapeseed) and in MITERRA: fallow and set aside. For INTEGRATOR and IMAGE, fallow land and non-food crops are included

Land use	Area (Mha)			
	INTEGRATOR	IDEAg	MITERRA	IMAGE

in agricultural land.

Animal livestock numbers

Source of livestock data (numbers of animals in the various animal categories) by the various models are:

- **INTEGRATOR** uses the FAO database at country level (<http://faostat.fao.org/>) (FAO, 2007).
- **IDEAg (CAPRI)** uses data from EUROSTAT on production statistics. For animals used for meat production, the data are slaughter heads per year and are converted to animal places using an average number of cycles per year for each country. Data for other animals (cows, sheep and goats for milk production, sows for piglet production, laying hens) are the average number of heads in the current year.
- **MITERRA** uses RAINS data at country level, whereas CAPRI data are used for distribution of animals over NUTS II regions
- **IMAGE** uses the FAO database at country level (<http://faostat.fao.org/>) (FAO, 2007), while making a division in dairy/non-dairy according to a procedure described in Bouwman *et al.* (2005). Animal numbers are three year running means thus leading to differences in the numbers used by INTEGRATOR

A comparison of results for the various models with respect to land areas used is given in Table 15&16.A2.

Table 15&16.A2 Data for the animal numbers used by INTEGRATOR, IDEAg, MITERRA and IMAGE for EU 27 in 2000.

Animal category	Number (Million heads)				
	INTEGRATOR ¹	IDEAg (2002) ²	MITERRA	IMAGE	EEA (2008)
Dairy cattle	28.1	25.9	27.4	28.2	28.4
Other cattle	69.2	60.5	68.6	68.9	66.9
Pigs	159.8	131.9	158.9	159.8	154.1
Poultry	1335.5	1435.3	1511.0	1193.2	1647.1
Sheep/goat	138.2	95.7	139.3	136.3	127.5 ³
Other animals ²	4.72	-	27.3	4.59	-

¹ Are equal to FAO numbers; excluding Cyprus

² INTEGRATOR: horses, MITERRA: horses and fur animals, IMAGE: horses, camels, mules and asses,

³ EEA includes buffaloes

Nitrogen fertilizer application

All models (INTEGRATOR, MITERRA, IDEAg and IMAGE) base their information on nitrogen fertilizer applications on FAO data. In both INTEGRATOR and MITERRA the national fertilizer consumption rates are derived from FAOSTAT. Within each country, the mineral fertilizer is distributed over crops using weighing factors, so that crops with highest N demand received highest amounts of N fertilizer. The weighing factors are calculated from the crop N uptake (= N in harvested

products + N in crop residues) and the total area of the crop. In IDEAg, estimates of N fertilizer application rates at country level are derived from FAO statistics for selected crops or groups of crops (FAO/IFA/IFDC/IPI/PPI, 2002). A so called Bayesian Highest Posterior Density (HDP) estimator is then used to minimize the differences between the estimated and given national application rates, ensuring via constraints that crop needs are covered and the available mineral and organic nitrogen is distributed. In IMAGE, country data for the agricultural land cover classes grassland, wetland rice, leguminous crops and other upland crops are based on FAO/ IFA/IFDC (2003) and used at that level. The various databases are described below.

- **FAOSTAT** is a database by the Food and Agriculture Organization of the United Nations (FAO). It contains a wealth of agricultural data, such as animal numbers for different animal categories, the amount of animal products (e.g. milk, meat and wool), fertilizer consumption, hectares of arable crops and the amount of crop products. The data are given for all countries and the time series ranges from 1960 till present. The fertilizer data concern also mineral N fertilizer.
- Most of the information available on the use of N contained in mineral fertilizers in Europe is obtained from the **European Fertilizer Manufacturer Association (EFMA)**.
- FAO publishes jointly with the **International Fertilizer Industry Association (IFA)**, the International Fertilizer Development Centre (IFDC), the Phosphate and Potash Institute (PPI) and the International Potash Institute (IPI) a report on the country-wise fertilizer use by crop for 88 countries including all member states of the EU (FAO/IFA/IFDC/IPI/PPI, 2002). The data are a consensus of the involved organizations and therefore reflect the general magnitude maintaining consistency with the national FAO consumption data.
- Each year each country that is party to the **UNFCCC** is obliged to submit a national greenhouse gas inventory including relevant background data that were used for the calculations (EEA, 2007, 2008). These data are usually compiled by (or for) the ministry of environment which is generally responsible for the commitments under the UNFCCC and the Kyoto Protocol, and often are different from the data submitted to FAO, which is done generally by the ministries of agriculture. Next to mineral fertilizer application data, the reports contain livestock numbers and manure excretion data for different manure management systems including pasture range and paddock.

Nitrogen excretion factors

- **INTEGRATOR and MITERRA** both calculate the total N excretion on NUTS 2 level from the number of animals and the N excretion per animal for the 8 animal categories of GAINS. The mean country-specific N excretion rates per animal category are also based on GAINS. GAINS calculates N excretion at country level by multiplying animal numbers in 8 animal categories (dairy cows, other cows, pigs, laying hens, other poultry, horses, sheep and goats and fur animals) with country-specific N excretion rates per animal category. A division is made between excretion of animals in housing systems and by grazing animals in pastures, using data at country level. The information in GAINS derives from an extensive consultation procedure involving country experts to provide their respective best estimates.

- **IDEAg (CAPRI)** assesses N excretion by using a mass-budget approach. The livestock system is regarded as a box with N input (feed from grazing, fodder, feed concentrates) and N output (products sold) for each animal type. The difference of both determines the amount of N excreted.
- **IMAGE** calculates the total N excretion at continental (or regional) level from the number of animals and the N excretion per animal for 9 animal categories (dairy and non-dairy cattle, buffaloes, sheep, goats, pigs, poultry, horses, asses, mules and camels). The continental specific N excretion rates per animal category are based on Van der Hoek (1998).

As an example, a scatter-diagram comparing N-excretion factors used at country level in INTEGRATOR (also used in MITERRA and derived from RAINS/GAINS) versus those by IDEAg (CAPRI) is given in Figure A 15.1.

For IMAGE, the data are only divided in Western and Eastern Europe. The figure shows that excretion rates for dairy cows are generally higher in CAPRI whereas for laying hens the opposite is true, especially for one county (Hungary).

NB: IPCC has established default N excretion factors to be used in national GHG inventories if no country-specific data are available. The guidelines describe however a methodology to derive N excretion on the basis of a more detailed animal characterization.

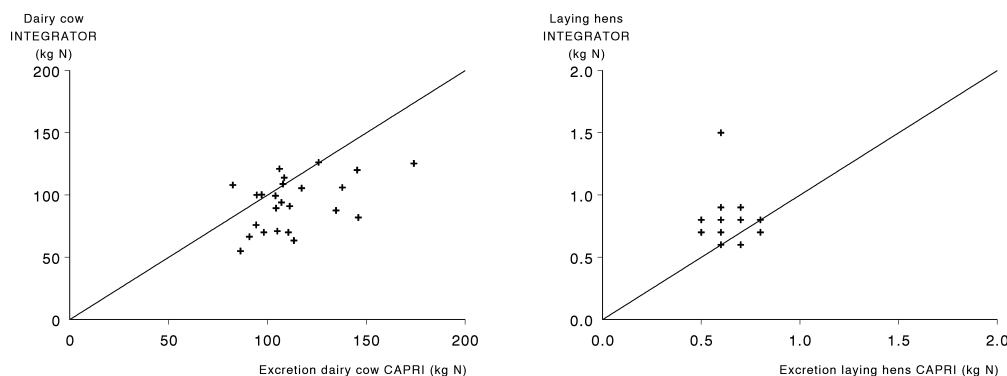


Figure 15&16.A1. N-excretion factors used at country level in INTEGRATOR versus those by IDEAg (CAPRI) for dairy cows (left) and laying hens (right).

Biological N Fixation rates

No spatial dataset for biological N fixation exists. Instead, methodologies have been used in each model to estimate biological N fixation rates either from crop-specific fixation rates, for non - leguminous crops or by linking the N fixation rate to the N content in the above-ground biomass of the crop for leguminous crops.

- As with MITERRA, **INTEGRATOR** assumes an average biological N₂ fixation in arable soils of 2 kg N ha⁻¹ by free living soil bacteria and of 5 kg N ha⁻¹ in grasslands. However, the N fixation of leguminous crops is calculated in more detail, based on a recent overview by Herridge *et al.* (2008). The total amount of N in seeds, being the product of crop yield and N seed content, is multiplied by the inverse of a crop specific harvest index (the ratio of seed dry matter to total above ground dry matter), a shoot +root/shoot ratio (to account for N fixation in roots)

and a crop specific percentage of N in the crop due to N fixation. Practically, the use of all these data implies that the amount of N fixed in dry pulses and soy bean equals 1.2 and 1.3 times the amount of N in the harvested products, respectively.

- In **IDEAg (CAPRI)**, biological N-fixation is calculated assuming a fixed fraction of aboveground nitrogen uptake for leguminous crops (75%) and fodder on arable land (5%).
- **MITERRA** assumes an average biological N₂ fixation in arable soils of 2 kg N ha⁻¹ by free living soil bacteria and of 5 kg N ha⁻¹ in grasslands. The amount of N fixed in leguminous crops, such as pulses and soya is assumed to be equal to the amount of N in the harvested products.
- The **IMAGE** model assumes an average biological N₂ fixation of 5 kg N ha⁻¹ by free living soil bacteria in both arable land and grassland and 25 kg N ha⁻¹ for wetland rice, based on Smil (1999). Analogous to IPCC, it uses a value that is twice the amount of N in the harvested products for pulses, soybeans and legumes, such as clover and alfalfa to account for all above and below-ground plant parts (Bouwman *et al.*, 2005).

NB: Crop-specific fixation rates are used by OECD, while linking the N fixation rate to the N content in the above-ground biomass of the crop, and thus to the yield that is achieved, is used by the IPCC.

- The OECD (2001) uses biological fixation rates per hectare of growing leguminous crops, which are available for a number of countries. Table 15&16.A3 shows the average data over all countries included in the database.

Table 15&16.A3 Average rates for biological nitrogen fixation (OECD, 2001), kg N.ha⁻¹.yr⁻¹

Leguminous Crops	BNF kg N.ha ⁻¹ .yr ⁻¹
Pulses	92
Soybeans	92
Clover	179
Alfalfa	239
Other Legume Crops	84
Free Living Organisms	4.0

- The **IPCC Guidelines** suggests biological N fixation, on average, supplies 50-60 per cent of the N harvested in grain legumes, 55-60 per cent of the N in N fixing trees and 70-80 per cent of the N accumulated by pasture legumes (Danso, 1995), and therefore the above-ground material is a good proxy for N-fixation by annually cultivated leguminous crops. Based on the assumption that the seed yield is about half the total aboveground biomass, N-fixation rates can be calculated with harvest data and a default N-content in the crop of 30 g N/kg dry biomass (IPCC, 1997, 2001).

Nitrogen deposition levels

The main source for the assessment of N deposition levels at the European scale are EMEP¹ model estimates based on NH₃ and NO_x emissions, as derived from an emission factor approach (see before). The combination of these emissions, coupled with an atmospheric dispersion model by EMEP leads to estimates at a geographic resolution of 50 km x 50 km (see Table 15.2). For more information on the EMEP model approach, we refer to chapter 14.

Crop yields

- **INTEGRATOR** and **MITERRA**. For grassland, no yield data are available. In INTEGRATOR and MITERRA, three types of grasslands are distinguished: intensively managed grasslands, extensively managed grasslands and rough grazing areas. The yield (net removal) of intensively managed grasslands is set at 4000 - 10.000 kg/ha, depending on the country, while the yield of the extensively managed grasslands varies from 2500 - 5000 kg/ha. The yield (net removal) of rough grazing areas is set at 0 (Velthof *et al.*, 2007; 2009). The yields of arable crops are derived from FAO statistics at a national basis, while aggregating the FAO crop types to CAPRI crops used in both models.
- **IDEAg (CAPRI)** yields are based on EUROSTAT production statistics. For the disaggregation to the spatial units, results of crop growth model simulations at water limited and irrigated conditions are used in combination with fraction of irrigated area to estimate crop yields for each soil unit.
- **IMAGE** uses the FAO crop yields per country in the past for the period 1970-2000. For the future, it predicts changes based on a calculated potential crop productivity multiplied by a so called “management factor”, being the fraction of actual yield to potential crop productivity. Additional to this external trend, yields also change because of the economically driven intensification as calculated by the GTAP model (Global Trade Analysis Project), through climate change and through change in agricultural area. Offtake of nitrogen in grasslands is assumed to be 60% of the sum of all N inputs to grassland minus the ammonia volatilization.

Nitrogen contents in crops

- **INTEGRATOR**: the N contents vary with the N input between a minimum value (at negligible N input) and a maximum value at an optimum effective N input. The maximum N contents in (intensively managed) grassland were set at 3%. The maximum N contents of crops were based on a literature review of Velthof & Kuikman (2000) for the Netherlands. The ratio between the minimum and maximum N content was set at 0.5 for grass land and fodder crops and of 0.7 for arable land. The ratio for arable land was applied to all arable crops.
- **IDEAg (CAPRI)**: constant N contents by crop for all countries are based on Britz *et al.* (2005)
- **MITERRA**: Data on N contents used for the CAPRI crops are country dependent and are based on Velthof & Kuikman (2000).
- **IMAGE**: Data on N contents used for the IMAGE crops are constant (independent of N input or country) and are based on Bouwman *et al.* (2005).

¹ The Co-operative Programme for the Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe). <http://www.emep.int/>

Nitrogen-emission fractions

All models use N emission fractions to assess the NH₃, NO_x and N₂O emissions to the atmosphere

- **INTEGRATOR** uses the same databases as MITERRA, with the exception of N₂O and NO_x emissions from the soil. INTEGRATOR uses emission factors that are derived as a function of N source (three fertilizer types, seven manure types, three crop residue types, mineralized soil organic N, biological N fixation and atmospheric deposition), manure application technique, soil type, pH, land use, precipitation and temperature, based on a large literature compilation, as described in Lesschen et al. (2010). The emission factor for NO_x is calculated from the N₂O emission factor assuming an average NO_x/N₂O ratio of 0.6. The ratio is based on results by Stehfest and Bouwman (2006), who found an average emission factor of 0.91% for 1008 N₂O emission measurements and of 0.55% for 189 NO emission measurements from agricultural fields.
- **MITERRA** and **IDEAg (CAPRI)** use all the NH₃ emission factors from RAINS/GAINS and this holds also for NO_x in case of MITERRA. MITERRA uses the general IPCC emission factors for N₂O. Emissions from N₂O, NO_x, and N₂ in IDEAg are based on the DNDC meta-model (Britz & Leip, 2009). In **GAINS** relevant datasets to predict NH₃, NO_x and N₂O emissions include: (i) number of housing days per animal category; (ii) volume of manure excretion per animal category; (iii) animal housing system; (iv) manure storage system; (v) manure categories (solid or slurry); (vi) type of fertilizers used and (vii) manure application techniques. In addition, it contains N (NH₃, NO_x or N₂O) emission fractions for housing systems per animal category and manure category and N (NH₃, NO_x or N₂O) emission fractions for N application for various manure, grazing and fertilizer categories. The N₂O emission fractions are partly based on general IPCC factors but partly on country information, thus being more specific. Factors are consulted with country-delegates.
- **IMAGE** uses varying N emission fractions for NH₃ that are based on Bouwman *et al.* (1997) for NH₃ volatilization from manure storage and manure excreted during grazing and on Bouwman *et al.* (2002) for NH₃ volatilization from fertilizer and animal manure application. Bouwman *et al.* (2002) 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 above mentioned data are included on a 0.5 x 0.5 degree resolution. N₂O emission fractions from housing systems are set constant but for soil, IMAGE uses a regression based approach, comparable to NH₃, based on the results of 1008 N₂O and 280 NO_x emission measurements from agricultural fields, reported in Stehfest and Bouwman (2006).

15&16.A3. Data sets to estimate N contents and N pools

The fluxes of nitrogen to the atmosphere are influenced by the carbon and nitrogen content of the soil. In biogeochemistry models, these soil parameters often are responsible for the highest contribution of the uncertainty of the model output of the

N₂O flux. Therefore, it is relevant to have information on these soil characteristics at the European scale. Furthermore, the variation in soil N pools is relevant to compare with the variation in soil N budgets. In this section, we present maps of present concentrations and pools of C and N in the soil and C/N ratios in the soil distinguishing between agricultural soils and non agricultural soils, based on various database, i.e. WISE and SOTER (World Soils and Terrain Database), European Soil Data Base (ESDB2), the soil profile analytical database (SPADE) and the ICP (International Cooperative Programme) forests database. First, we explain the methodology and then we present the maps for inter-comparison.

WISE/Spade database: all soils over Europe

An indication of the nitrogen pools in both agricultural soils and forest soils has recently been derived on the basis of the WISE soil profile database of ISRIC (International Soil Reference and Information Centre) (Batjes, 2009), which consists of about 9600 measured soil profiles from all over the world and the SPADE soil profile analytical database of the International Food Policy Research Institute, IFPRI (Hiederer *et al.*, 2006), with about 1200 measured soil profiles located in Europe. For each profile an extensive set of attributes has been recorded, such as CEC, pH, base saturation and C content and N content. A geostatistical model was developed and applied to predict five basic soil properties for three soil horizons at the European scale and quantify the associated prediction uncertainties (Heuvelink *et al.*, 2010). The five soil properties are pH, organic carbon, organic nitrogen, clay content and bulk density. The geostatistical model takes a regression co-kriging approach, in which correlations between soil properties and across soil horizons are taken into account. Non-stationarities in the means and variances are represented by mapping units of the generalized European soil and land cover maps. Conditional sequential Gaussian simulation was used to generate possible realities of the soil properties on a 5 km by 5 km grid. The procedure allowed calculating spatially explicit cumulative frequency distributions, including the median and a confidence interval (e.g. 5%-95%) for N contents and pools (for a depth of 50 cm). Maps of the median C and N contents in the A horizons of European soils thus derived are given in Figure A 15.2.

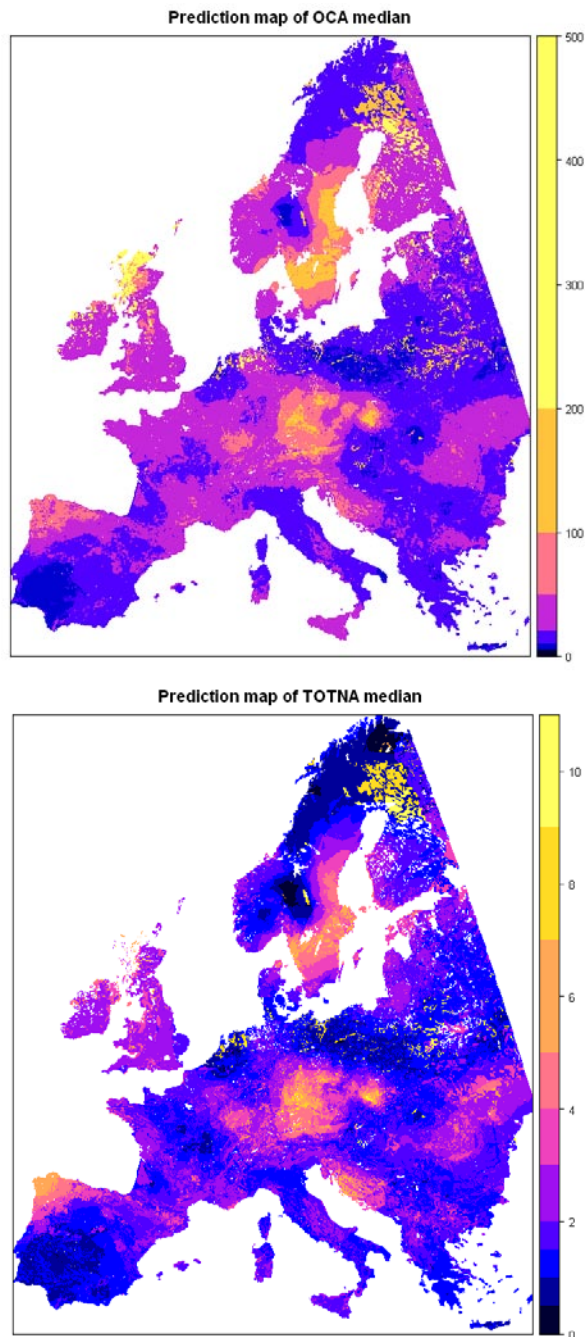


Figure 15&16.A2 Maps of the median C and N contents in the A and B horizon of European agricultural soils and forests soils as derived with the WISE and SPADE databases.

European Soil Database : agricultural soils

Soil organic nitrogen (SON) data have also been calculated from the map of Soil Organic Carbon (SOC) in agricultural soils, and Soil Bulk Density using C/N ratios for agricultural soils for the top 50 cm. The soil organic carbon map is based on the European Soil Database SPADE, using pedotransfer rules comprising soil type and land use indices, which are modulated with a climate index, as described in Jones et

al. (2005). For land use, the information of Corine1990 was used. However, much better land use maps are available now (e.g. Corine2000, Leip et al., 2008).

Applying a model for N turnover in soils based on a more recent land use map bears the risk of inconsistent results. Therefore, the map has been derived by (a) filtering out the SOC values for agricultural land (annual crops; maps for other land use types are obtained in analogy) and (b) interpolating missing values by using a similarity-index for the soil types. A map of the SOC concentration for the topsoil of agricultural soils thus derived is given in Figure A 15.3 (a). This was converted to soil carbon and nitrogen pools assuming (i) 99% of the carbon is in the humus fraction (CN-ratio of 10) and 1% of carbon is in the resistant litter fraction (CN-ratio of 100)² (ii) constant topsoil carbon concentration until the ploughing depth of 0.2 m; (iii) exponential decrease of the carbon concentration with depth below the ploughing depth, halving the concentration every 10 cm. The map of SON pool thus derived is given in Figure A15.3 (b).

² CN-ratios and other assumptions in this calculation in analogy to the regional mode the DNDC-version 89..

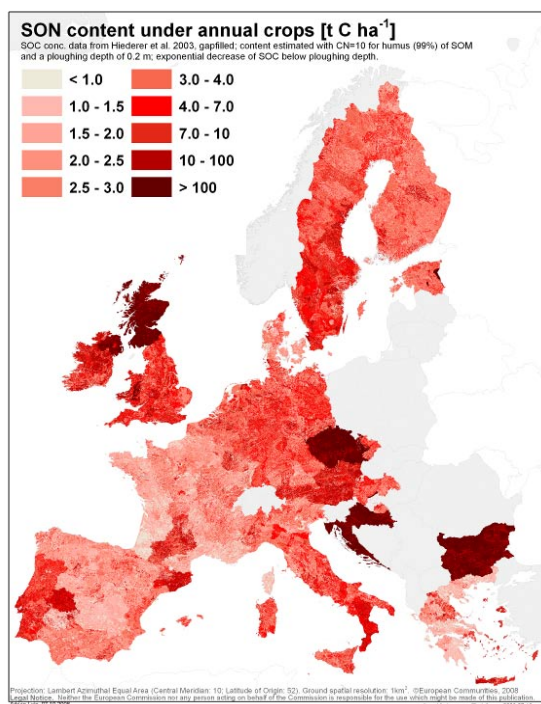
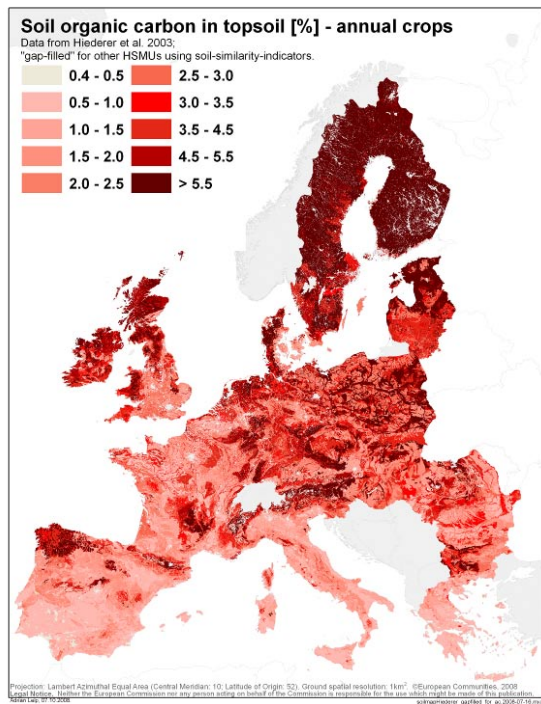


Figure 15&16.A3 (a) Map of soil organic carbon (SOC) under annual crops, based on Jones *et al.* (2005) (b) Estimation of SON on the basis of (a) – explanation in the text.

ICP Forest Level I soil database: forest soils

The European ICP Forest Level I soil data base was exploited with the objective to estimate the regional distribution of forest soil carbon in Europe. The main purpose was to evaluate, which Level I data are available and can be used to assess such a baseline for Europe. The evaluations have focused on filling data gaps, in particular for bulk density by using pedotransfer functions. The plot data were then upscaled (regionalised) using the European soil map 1:1,000,000 and, at the same time, considering biogeographic aspects for stratification. For that, climate regions from the European soil regions map project were used. Besides the calculation of soil carbon stocks for all plots, a map of the regional distribution of soil carbon stocks (O-layer + 0-20 cm) and topsoil carbon concentrations (0-5/0-10 cm) was produced (Baritz et al., 2010). The map of soil organic carbon thus derived, based on ICP forest plots, is given in Figure A 15.4.

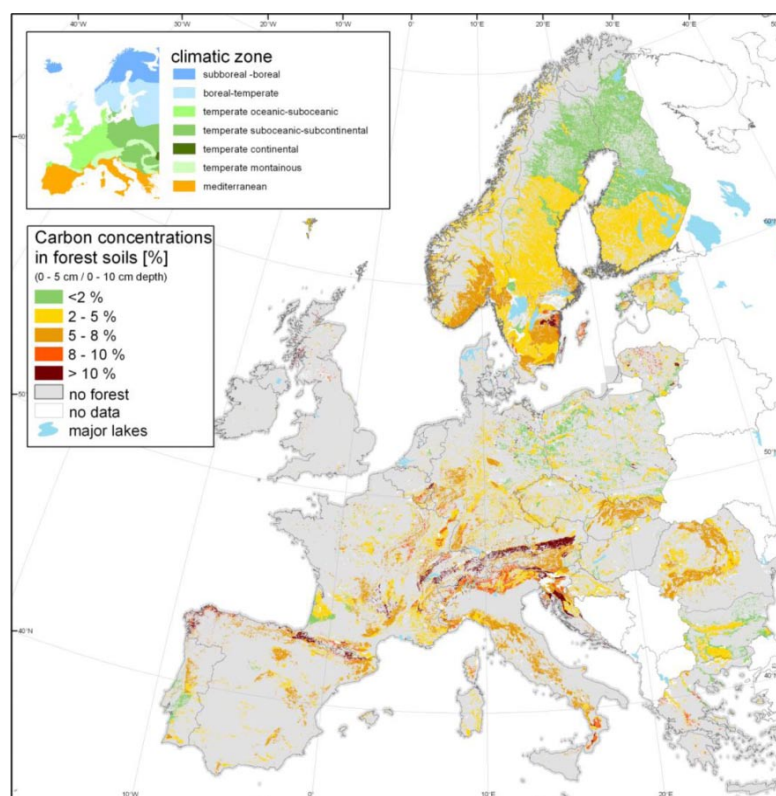


Figure 15&16.A4 Map of SOC pools in forest soils, based on Baritz *et al.* (2010).

15&16.A4. Uncertainties in mapping European agricultural NO_x emissions

Most uncertain appear to be the NO_x emissions as shown in the main text. This is in line with results obtained by Butterbach Bahl *et al.* (2009). These authors applied the DNDC model at 15 EU countries and also included the approach used by: (i) IMAGE, being an empirical emission model after Stehfest and Bouwman (2006), (ii) (Simpson *et al.*, 1999), using the approach that 0.3% of any form of nitrogen is volatilized as NO and (iii) Yienger and Levy (1995), being another empirical emission model accounting for nitrogen fertilization rate, temperature effects and the pulsing of NO emissions following prolonged dry periods. The interesting aspect of the model approach by Butterbach Bahl *et al.* (2009) is that they used the same input data for all

models, implying that results are only influenced by the model approach. A comparison of the results is given in Figure A 15.5.

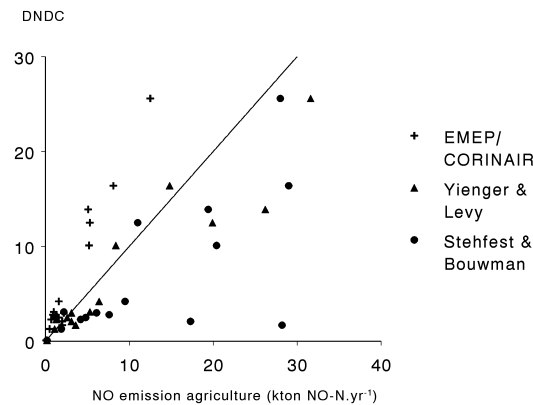


Figure 15&16.A5 A comparison of country emissions for NO for the year 2000 within EU 27 as derived with INTEGRATOR with other model approaches. Data are taken from Butterbach Bahl *et al.* (2009).

The impact of model approach on the regional pattern of NO emissions is illustrated by results derived with the DNDC model (Li, 2000) and three other methods (Figure A15.6) that have been described before (Butterbach-Bahl *et al.*, 2009). Prior to its application the DNDC model was tested with datasets on N trace gas emissions as obtained for a series of field sites world wide (Li *et al.*, 2005). Results are derived by coupling DNDC to a detailed GIS (10 km by 10 km resolution) holding all relevant information for initialising (crop and soil properties) and driving the model (daily meteorological data, field management and fertilizer application). Results show widely varying patterns of NO emission, illustrating the uncertainty in NO emissions from agricultural soils. For more information on the background of the various approaches and the reason for the differences in model outcomes: (see Butterbach-Bahl *et al.*, 2009).

15&16.A5. Uncertainties in mapping European forest N₂O and NO_x emissions

Regional pattern of the N₂O and NO emissions for forests calculated with Forest-DNDC are presented in Figure A15.7. Unlike to INTEGRATOR (see main text), the results show high N₂O, and to a lesser extent also NO, emissions in the Nordic countries, which seems to be due to the fact that the N balance has not been checked in DNDC.

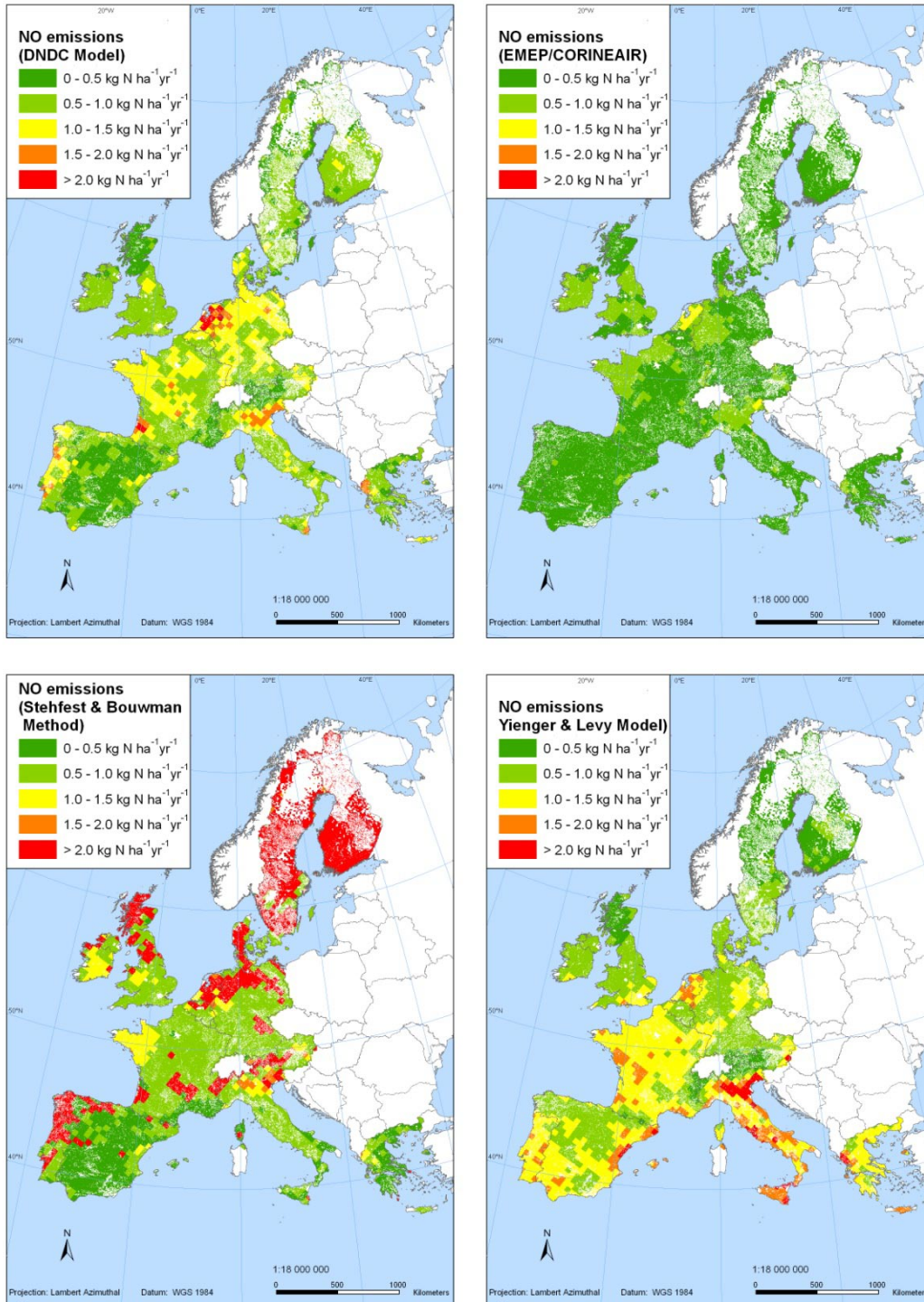


Figure 15&16.A6 Regional pattern of simulated NO emissions from agricultural soils in the year 2000, either using the DNDC model or the Skiba-EMEP/CORINAIR, Yienger and Levy and Stehfest and Bouwman approaches. Based on Butterbach-Bahl *et al.* (2009).

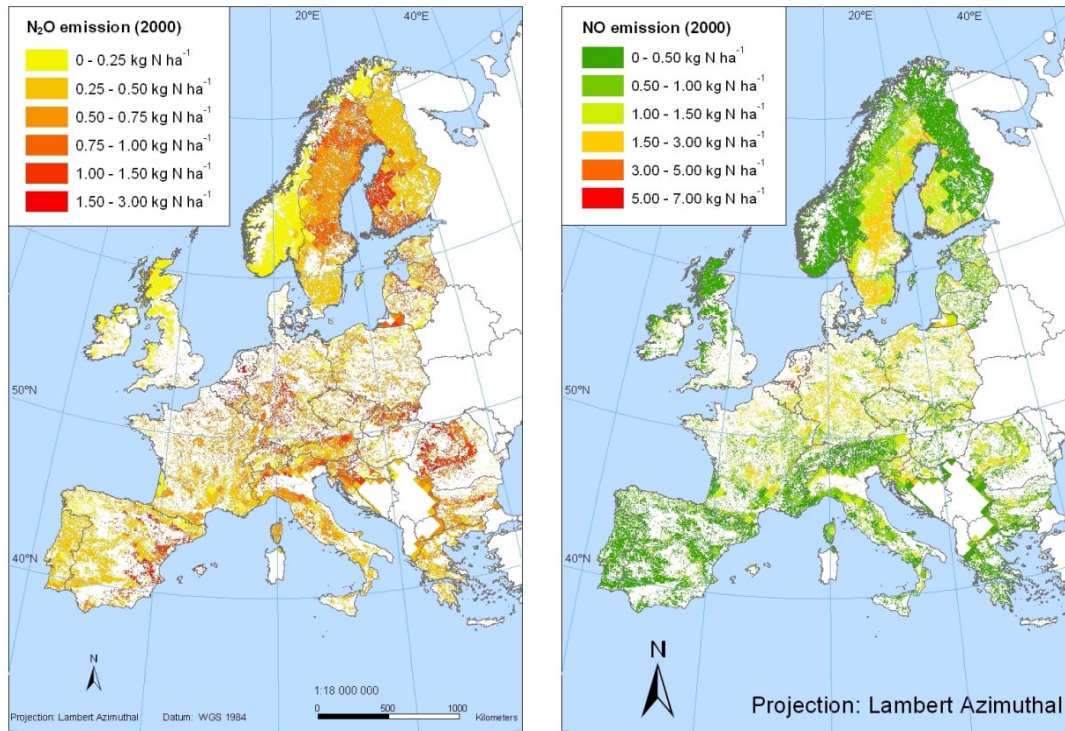


Figure 15&16.A7 Regional pattern for the emissions from forest soils in the year 2000 of N₂O (left) and NO (right) as derived with DNDC (after Kesik *et al.*, 2005). Note the difference in legend.

15&16.A6. Comparison of total atmospheric Nr emissions fluxes by various data sets

Here we include a comparison of N emissions on a country scale for the 27 EU countries plus Switzerland, Norway and Croatia, with various data sources, including:

- EDGAR³ V4.0 for NH₃, N₂O and NO_x
- GAINS for NH₃, NO_x and N₂O⁴
- OECD⁵-UNFCCC/IPCC⁶ and EDGAR for N₂O and NO_x,
- EMEP^{7,8} for NH₃ and NO_x

IMAGE has no data per country for total emissions and is thus not included. INTEGRATOR only includes emissions from terrestrial systems but total emissions are also derived by adding GAINS non terrestrial emissions. A comparison of total emissions for NH₃, N₂O and NO_x within EU 27 as derived with INTEGRATOR compared to GAINS, EDGAR, OECD/IPCC and EMEP for the year 2000 is presented in Figure A 16.1.

³ <http://http://edgar.jrc.ec.europa.eu/> currently the draft version is used.

⁴ <http://www.iiasa.ac.at/web-apps/apd/gains/EU/index.login?logout=1>

⁵ http://stats.oecd.org/wbos/Index.aspx?datasetcode=ENVPERFINDIC_TAD_2008

⁶ http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php

⁷ http://www.emep.int/index_data.htm

⁸ <http://www.emep-emissions.at/emission-data-webdab/emissions-used-in-emep-models/>

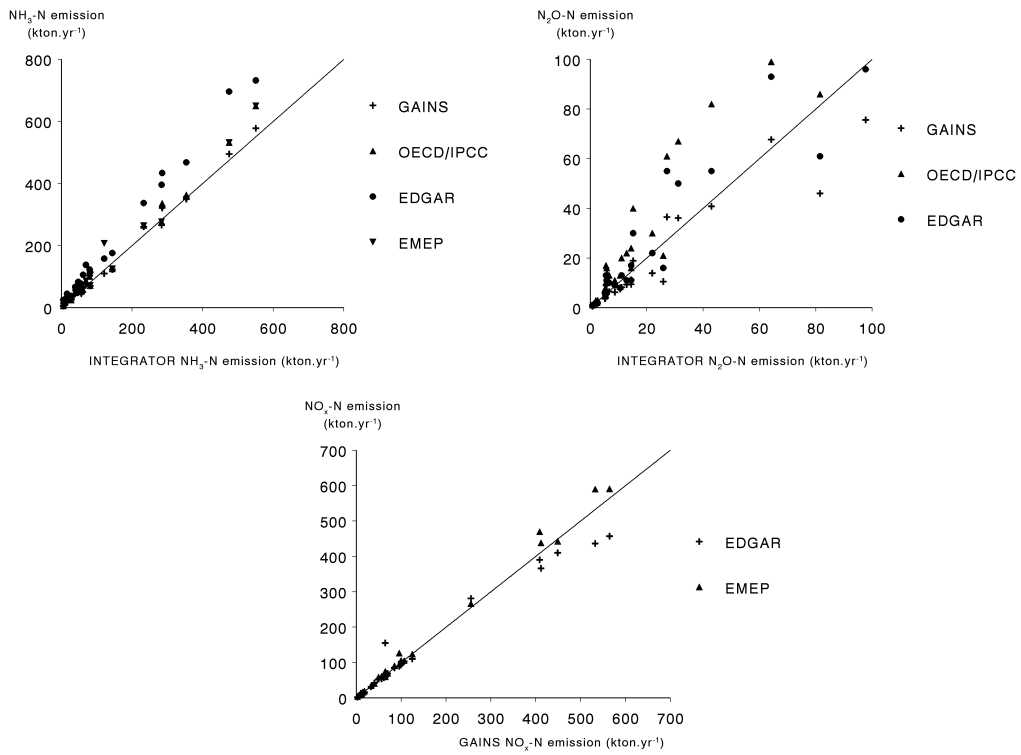


Figure 15&16. A1. A comparison of total emissions for NH₃, N₂O and NO_x within EU 27 as derived with INTEGRATOR compared to EDGAR, GAINS, OECD/IPCC, and EMEP for the year 2000.

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Annex 1 Summary of abbreviations

Organisations

OECD	Organisation for Economic Co-operation and Development.
OSPARCOM	Oslo and Paris Conventions for the Prevention of Marine Pollution.
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel on Climate Change
FAO	Food and Agriculture Organization of the United Nations
EFMA	European Fertilizer Manufacturer Association
IFA	International Fertilizer Industry Association
IFDC	International Fertilizer Development Centre
PPI	Phosphate and Potash Institute
IPI	International Potash Institute
ISRIC	International Soil Reference and Information Centre
IFPRI	International Food Policy Research Institute
ICP	International Cooperative Programme
UNECE	United Nations Economical Commission for Europe
CLRTAP	Convention on Long-range Transboundary Air Pollution

Systems/ databases etc

MINAS	Mineral Accounting System.
WISE	World Information Soil Database
SOTER	World Soils and Terrain Database
ESDB	European Soil Database.
CLC2000	Corine Land Cover 2000.
EUROSTAT	Detailed statistics on EU scale
LUCAS	Land Use/Cover Area Frame Statistical Survey
SPADE	Soil Profile Analytical Database
HSMU	Homogeneous Spatial Mapping Unit

Models

CLUE	Model describing Conversion of Land Use change and its Effects
INTEGRATOR	Integrated Nitrogen Tool across Europe for Greenhouse gases and Ammonia Targeted to Operational Responses
CAPRI	Common Agricultural Policy Regionalised Impact model
DNDC	Denitrification Decomposition model
IDEAg	Indicator Database for European Agriculture
MITERRA	Mitigation model
IMAGE	Integrated Model to Assess the Global Environment
GTAP	Global Trade Analysis Project model
GAINS	Greenhouse gas, Air pollution INteractions and Synergies
EMEP	European Monitoring and Evaluation Programme
EDGAR	Emission Database for Global Atmospheric Research
EPIC	Environmental Policy Integrated Climate Model
GREEN	Geospatial Regression Equation for European Nutrient losses