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A comparison of disaggregated nitrogen budgets for Danish agriculture using Europe-wide and national approaches

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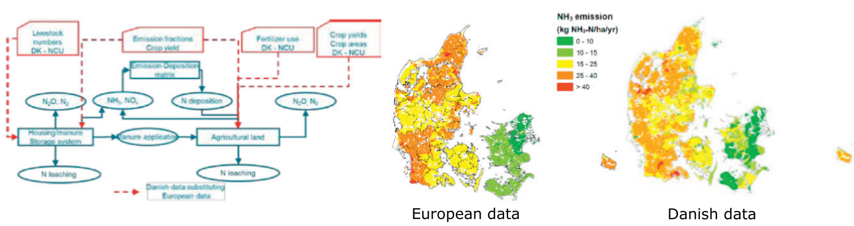
HIGHLIGHTS

- Spatially disaggregated agronomic nitrogen (N) budgets for Denmark are compared.
- Effects of using national rather than EU input data are analysed.
- Detail of data causes large differences in N excretion and N losses to air and water.
- Results obtained with detailed Danish input data were closer to observed distributions.
- Good policy support requires high spatial resolution input data.

GRAPHICAL ABSTRACT



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ABSTRACT

Spatially detailed information on agricultural nitrogen (N) budgets is relevant to identify regions where there is a need for a reduction in inputs in view of various forms of N pollution. However, at the scale of the European Union, there is a lack of consistent, reliable, high spatial resolution data necessary for the calculation of regional N losses. To gain insight in the reduction in uncertainty achieved by using higher spatial resolution input data. This was done by comparing spatially disaggregated agricultural N budgets for Denmark for the period 2000–2010, generated by two versions of the European scale model Integrator, a version using high spatial resolution national data for Denmark (Integrator-DK) and a version using available data at the EU scale (Integrator-EU). Results showed that the national N fluxes in the N budgets calculated by the two versions of the model were within 1–5% for N inputs by fertilizer and manure excretion, but inputs by N fixation and N mineralisation differed by 50–100% and N uptake also differed by ca 25%, causing a difference in N leaching and runoff of nearly 50%. Comparison with an independently derived Danish national budget appeared generally to be better with Integrator-EU results in 2000 but with Integrator-DK results in 2010. However, the spatial distribution of manure distribution and N losses from Integrator-DK were closer to observed distributions than those from Integrator-EU. We conclude that close attention to local agronomic practices is needed when using a leaching fraction approach and that for effective support of environmental policymaking, Member States need to collect or submit high spatial resolution agricultural data to Eurostat.

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1. Introduction

Spatially detailed information on nitrogen (N) budgets is relevant to identify regions with a high potential to significantly reduce N pollution and increase N efficiency. Moreover, to be relevant for policymakers, there is a need to disaggregate national N budgets, at least to the scale of the administrative NUTS3 regions (Nomenclature of Territorial Units; EC, 2017) that are often responsible for local health and business development and local environmental regulation. Furthermore, disaggregation to biophysical regions such as landscapes and/or catchments is relevant, since implementation of the Water Framework Directive (EC, 2000) and to a lesser extent the Nitrates Directive (EC, 1991) will lead to significant changes in land use and land management at this scale.

Regarding the assessment of agricultural N budgets within a country it is important to identify the most appropriate scale in view of the impact of N inputs on air quality and water quality. For nitrous oxide (N_2O), information on the spatial distribution of the emissions is less relevant, because N_2O is a long-lived gas with strong atmospheric dispersion, leading to an averaging of its concentration. For NH_3 emissions, and related N deposition, and for N leaching and N runoff, accurate information on their spatial distribution is, however, crucial in view of eutrophication impacts on terrestrial and aquatic ecosystems close to its source (Cellier et al., 2011; De Vries et al., 2015; Kros et al., 2013). 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 (De Vries et al., 2010). This effect holds for all spatial levels and may especially affect the results of European scale model predictions. For this reason, many countries in Europe have developed modelling tools, at national and sub-national scale.

One model that has been used at European scale to assess N budgets is the model Integrator (De Vries et al., 2011; Kros et al., 2012), which includes the MITERRA model (Velthof et al., 2009) for agricultural regions, modified to include much more spatial detail. Where MITERRA focuses on ca 300 NUTS2 regions, Integrator includes ca 40,000 NitroEurope Classification Units (NCUs), which are unique combinations of soil mapping units (Soil Geographical Database of Europe, SGDBE; Daroussin et al., 2006; EC, 2006) and slope classes (Vogt et al., 2007) within ca. 1300 NUTS3 regions (EC, 2017). These NCUs are composed of polygons, being clusters of 1 km by 1 km pixels. The model includes detailed downscaled information on animal numbers at NCU level, upscaled from 1 km by 1 km information (Neumann et al., 2011). Despite using this detailed information, the model might be quite inaccurate at the regional level within countries (cf. Kros et al., 2012).

To gain insight in the reduction in uncertainty that could be achieved by using higher resolution input data, spatially disaggregated agricultural N budgets for Denmark for the period 2000–2010 were generated by the European scale model Integrator, using both high spatial resolution national data (Integrator-DK) and data available at the European scale (Integrator-EU). Here we report the approach and results of this study, focusing on the years 2000 and 2010, for which the quality of the regional Danish input data was considered best. The results provide insight into the quality of European-scale model results at regional scale (within country level). We also compared the results at national scale with those obtained using Danish national data and a Danish modelling approach.

2. Materials and methods

2.1. Integrator EU

The Integrator model uses relatively simple and transparent model calculations based on existing model approaches, combined with high-resolution spatially explicit input data. It includes sub-models for the prediction of ammonia (NH_3), nitrous oxide (N_2O), other oxides of N (NO_x) and dinitrogen (N_2) emissions and N leaching from the root zone (principally nitrate, NO_3^-) and runoff from animal housing, manure storage systems and agricultural soils, based on the MITERRA-Europe model (Lesschen et al., 2011a; Velthof et al., 2009) and from non-agricultural terrestrial systems, including deposition, fixation, (im)mobilisation and emissions and leaching for forests and semi-natural vegetation. An emission and deposition matrix for NH_3 and NO_x, based on the EMEP model (Simpson et al., 2006), is used to assess the interactions through the atmosphere between agricultural and non-agricultural land.

Integrator calculates the total manure production for each NUTS3 region, using Eurostat data on animal numbers at NUTS3 level and excretion rates from the CAPRI model (Britz and Witzke, 2012). The manure production is calculated at the NCU level, using livestock numbers downscaled from NUTS3 level and national values for N excretion per animal type. A division is made between excretion of animals in housing systems and animals grazing pastures, based on data at the country level that is derived from the GAINS model (Klimont and Brink, 2004). Manure produced in housing and manure storage systems at NCU, corrected for nutrient losses (gaseous and leaching) in animal housing and storage systems, is first distributed within a NUTS3 region, until a maximum manure application is reached. If excess manure exists within an NCU, the excess is distributed over nearby NCUs within the same NUTS3 region that have the capacity to utilise more manure. If an excess exists at NUTS3 level, the remaining excess is distributed to nearby NUTS3 regions within the country. There is no manure transport between countries included in the model. When an excess at country level exists, being only the case for a few countries, this manure is removed from the system. More detail is given in Section 1 of the Supplementary material (SM).

The maximum amount of manure N applied to agricultural land was set to the 170 kg N ha^{-1} $year^{-1}$ specified in the EU Nitrates Directive (EC, 1991), except for grassland and other roughage crops in Belgium, Denmark, Germany, UK, Ireland, Italy and Netherlands. Here, values of 230 or 250 kg N ha^{-1} $year^{-1}$ are used, depending on the derogation received from the EU. These maximum manure applications rates were assigned irrespective of the occurrence of nitrate vulnerable zones (NVZ).

The actual manure application rates, being equal to the N excreted minus N emissions in housing systems and by grazing, depends on the crop and grassland type specific weighing factors (see SM Section 1 for more details). The N fertilizer application at NCU level is based on the total N crop offtake, the available non-N fertilizer inputs (N inputs by animal manure, crop residues, N mineralisation, N deposition and N fixation) and the N use efficiency (NUE) of the effective N input. The results thus obtained were corrected, where needed, by making use of national fertilizer consumption rates for the year 2000 or 2010 (FAO, 2010).

The N crop offtake is calculated as the product of the crop yield (in terms of harvest) and the N content in harvested crops, which in turn is a function of the N input. The total demand in a NUTS3 region is calculated by multiplying the N removal of each crop by the total area of the crops in each NUTS3 region. The areas of crops in NUTS3 regions are derived from CAPRI. The yields of arable crops for each country are derived from FAOSTAT (FAO, 2010). The N contents of harvested crop products and the amount of crop residues and the relation with N input are based on literature (Fink et al., 1999; Greenwood and Draycott, 1989; Velthof and Kuikman, 2000). The N in crop residues is calculated by dividing the N removed in harvest with an N index.

The emission of gaseous N compounds (NH_3, N_2O, NO and N_2) accounted for in the model include emissions (i) from faeces and urine during storage in housing and manure storage systems, (ii) by grazing animals, (iii) after application of manure and fertilizers to agricultural land and (iv) due to atmospheric deposition, N fixation and crop residue input (not included for NH_3).