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Management of Agricultural Nitrogen Losses in European Landscapes: An Ecosystem Modelling Case Study

Tommy Dalgaard[a], Nick Hutchings[a] and Chris Kjeldsen[a]
[a]University of Aarhus. Department of Agroecology and Environment. Faculty of Agricultural Sciences (DJF). P.O. Box 50, DK-8830 Tjele. Denmark. E-mail: tommy.dalgaard@agrsci.dk

Abstract: Management of Nitrogen (N) losses and the related greenhouse gas emissions is one of the most important environmental issues related to agriculture. This paper shows examples of an integrated model tool, developed to quantify the N-dynamics at the complex interface between agriculture and the environment, and quantify effects of different management practices. Based on results from the EU funded research projects NitroEurope (www.NitroEurope.eu) and MEA-scope (www.MEA-scope.org), examples from the quantification of farm N-losses in European agricultural landscapes are demonstrated. The dynamic whole farm model FASSET (www.FASSET.dk), and the Farm-N tool (www.farm-N.dk/FarmNTool) are used to calculate farm N balances, and distribute the surplus N between different types of N-losses (volatilisation, denitrification, leaching), and the related greenhouse gas emissions. Results show significant variation among landscapes and management practices. Moreover, significant effects of the non-linearities, appearing when integrating over time, and scaling up from farm to landscape, are demonstrated. Finally, general recommendations for landscape-level management of farm related nitrogen and greenhouse gas fluxes are made, and discussed in relation to ongoing work in European research projects and in relation to ecosystem services.

***Keywords**:* environmental management; agriculture; nitrogen; greenhouse gases; ecosystem services.

1. INTRODUCTION

During the last couple of decades, significant research has been put into the quantification of ecosystem services and environmental pollution from agriculture. In this context, the present paper especially focuses on the possibilities to quantify and mitigate N-losses and the related greenhouse gas emissions, and thereby linking provision services (production) and supporting services (matter dispersal and cycling) from agricultural landscapes.

The results presented are synthesized from two major European research projects, where models to describe and analyse the nitrogen cycling in agricultural landscapes have been developed. Both in the landscape component of NitroEurope (www.NitroEurope.eu), and in the MEA-scope project (www.MEA-scope.org), integrated farm modelling tools have been developed and implemented in a number of European landscapes from which we will present results in this paper.

2. MATERIALS AND METHODS

2.1 Landscape data collection

In the landscape component of the NitroEurope Integrated Research Project (Drouet et al. 2010) we study six agricultural landscapes; respectively in Denmark, The Netherlands, Scotland, Poland, Naples in Italy, and Brittany in France (Figure 1). Two of these landscapes, respectively in Denmark and Poland, were also studied in the MEA-scope research project (Piorr and Müller 2009), which in addition covered five other landscapes situated in Hungary, Slovakia, Tuscany in Italy, Combrailles in France, and Brandenburg in Germany, where landscape effects of agricultural production was investigated (Figure 1).

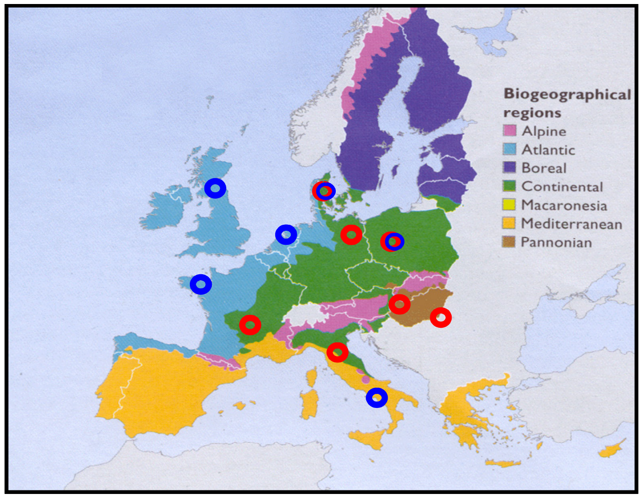

Figure 1. Geographical location of the European agricultural landscapes, studied in the research projects of NitroEurope (marked blue, Drouet et al. 2010) and MEA-scope (marked red, Piorr and Müller 2009).

For the landscapes studied (Figure 1), detailed information about land use, soil types, hydrology and meteorology have been collected (Dalgaard et al. 2007a). The landscapes varied in size from about 25 to 900 km^2, with a map resolution varying from1:10000 in the Danish landscape to about 1:100000 for some of the Eastern European sites. Detailed farm management data have been collected via farm interviews (Dalgaard et al., 2007b), whereas more general farm data have been collected from the available European (McClintoch 1989) or national farm databases (Dalgaard and Kjeldsen 2008). In parallel, digital soil, hydrology and weather data have been collected from Pan-European databases, or more detailed databases where available (Dalgaard et al., 2007b). For example, weather data for the period 1983 to present have been collected from the Pan-European 50 km x 50 km MARS climate data grid (Joint Research Centre 2010, Figure 2).

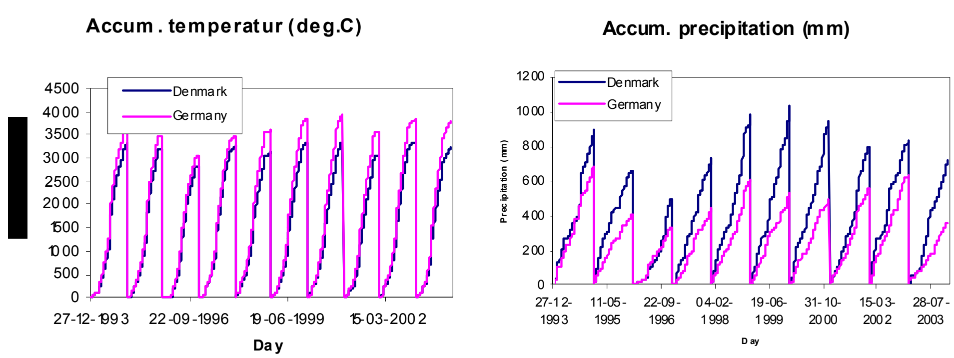

Figure 2. Temperature sum and precipitation sum curves for the 10 years (1994-2004) where simulation results are exemplified in the German and the Danish case landscapes (see results session). Figures are derived from the Pan-European 50 km x 50 km MARS climate data grid (Joint Research Centre 2010). Danish landscape data was derived from grid no. 70058; German data was derived from grid no. 63062.

1.6 The farm nitrogen balance and modelling framework

The farm N balance is calculated on an annual basis as the difference between farm gate inputs and outputs (equation 1). In this study, the Farm ASSEssment Tool (www.fasset.dk) and the Farm-N model (www.farm-N.dk/FarmNTool) are used in parallel to distribute the surplus N into the different types of losses (Figure 3, equation 1), where each farm is modelled separately.

Equation (1):
Farm N balance = N outputs – N inputs = N surplus =
N products – N feed – N fertiliser – N manure – N fixation – N deposition =
Ammonia emission + N leaching + denitrification – soil N change

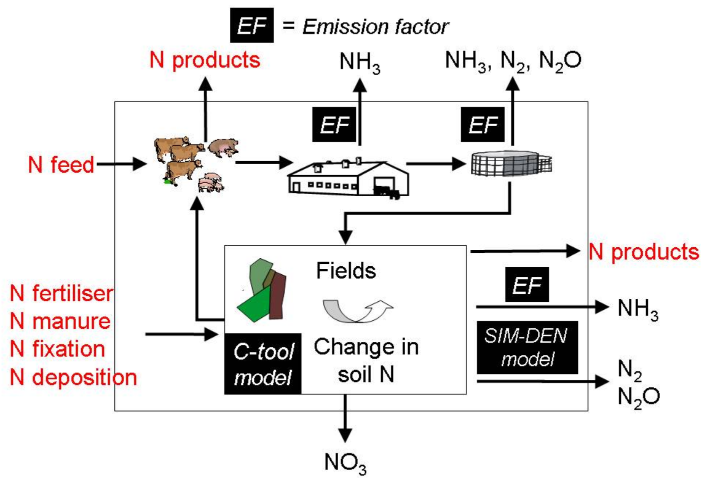

Figure 3. The farm nitrogen balance, and its distribution into types of losses by the Farm-N and FASSET models. The N-balance is calculated as the sum of N in products – N feed – N fertiliser – N manure – N fixation – N deposition (see equation 1). In the models, this balance is distributed into different types of losses in the form of ammonia (NH_3) emission, nitrates (NO_3^-) leaching, denitrification to free nitrogen (N_2) or nitrous oxide (N_20), or changes in the soil-N pools. This modeling is based on emission factors (EF) in combination with the C-tool (Pedersen 2008) and SIM-DEN (Vinther & Hansen 2004) component models.

The FASSET-model is a dynamic, deterministic model running at a daily time step (Zander et al. 2009). In this study, FASSET is used to illustrated effects of temporal differences in management practices within the growing season of agricultural crops. In contrast, the Farm-N model is designed to calculate yearly values for farm N-balances, but with no within year interactions and feedback mechanisms included between the N-flow components of Figure 3. In this study, the two models do not interact, however, both FASSET and Farm-N distribute surplus N into the same categories of N-losses illustrated in Figure 3, and the results are thereby comparable (for more details see Zander et al. 2009).

In the NitroEurope landscape component, the FASSET farm management model is integrated into a whole landscape nitrogen simulation tool called NitroScape (Figure 4). Based on the simulations in this paper, we will discuss this integration, and the implications of taking into account the effects of spatio-temporal heterogeneity and differences among the landscapes studied.

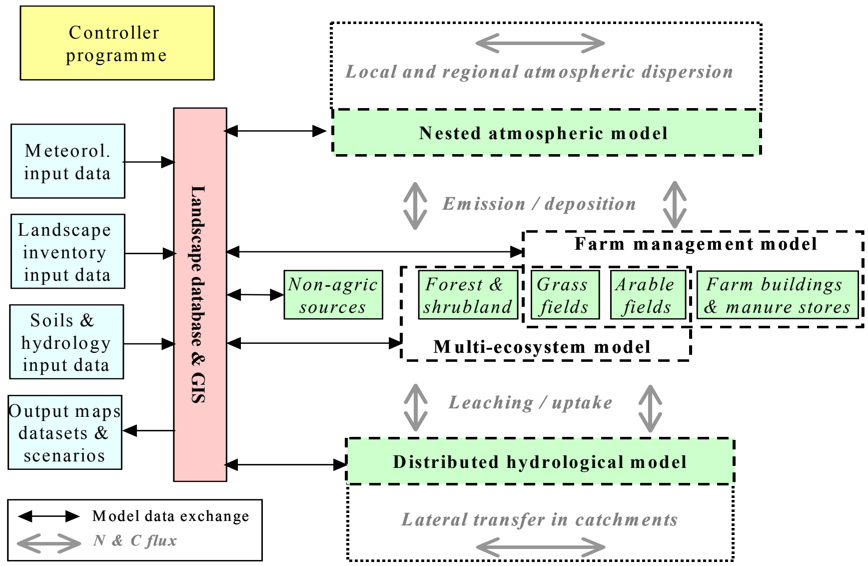

Figure 4. NitroScape: The NitroEurope whole landscape simulation tool, designed to model nitrogen (N) and carbon (C) fluxes and the related emissions of greenhouse gasses, with FASSET integrated as the "farm management model" (Drouet et al. 2010)

3. RESULTS

3.1 Effects of differences between landscapes and farm structures

The differences in land use, livestock densities and the average N-surplus for the seven MEA-scope study landscapes are summarised in Table 1 (Dalgaard et al. 2007a, 2008). A significant between landscape variation is noticed, but with no clear correlation between the overall livestock density and N-surplus, which would have been expected based on the results from Dalgaard et al. (1998, 2002, 2008). For example, the Danish and the Polish landscapes, which have similar amounts of land use, have the same average N-surplus (81 kg/ha/yr and 80 kg/ha/yr, respectively), even though the average livestock density for the Danish landscape is significantly higher than for the Polish landscape (2.8 slaughter pigs per ha in the Danish area compared to 0.9 slaughter pigs per ha in the Polish area, and equal cattle densities in the two areas). However, there is a clear picture that high cattle density leads to a relatively higher N-surplus (remark for example the high value in Combrailles).

Table 1. Differences in land use, livestock density & modelled farm N-surpluses in the seven European landscapes included in the MEA-scope project (Dalgaard et al. 2007a, 2008).

Landscape	Brandenburg	Turew	Piestany	Borsodi M.	Mugello	Combrailles	Viborg
Country	DE	PL	SK	HU	IT	FR	DK
Land Use (% of area):							
- Agriculture excl. grasslands	44	68	66	21	16	28	78
- Pastural grasslands	16	9	1	37	10	44	4
- Other areas	40	24	32	42	73	28	18
Livestock Density (#/ha):							
- Cattle > 1 year in age	0.5	0.3	0.2	0.1	0.2	0.6	0.3
- Slaughter pigs	0.1	0.9	0.8	0.3	0.1	0.1	2.8
N-surplus (kg N/ha/yr)	107	81	85	61	32	127	80

To investigate the reasons for the similar average N-surpluses in the Danish and the Polish landscape, a scatter plot over individual farm nitrogen balances versus livestock densities has been made for each of the two landscapes (Figure 4).

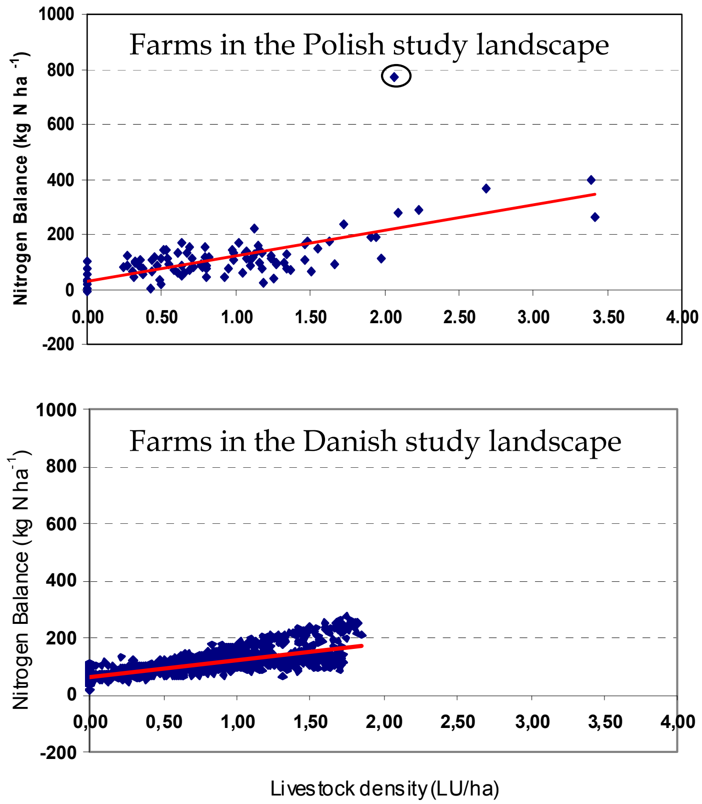

Figure 4. Example on the variation in farm nitrogen balances versus livestock density in the Polish (top) and Danish (bottom) study landscapes (Bienkowsky et al. 2010, Dalgaard et al. 2008). 1 livestock unit (LU) corresponds to 100 kg N spread in the form of livestock manure. The Polish outlier marked with a circle represents a farm with a very small farm area compared to the livestock number, and a high export of manure from the farm. Moreover, the linear correlations between the points are shown for both landscapes.

The scatter plots in Figure 4 show large variation in the livestock densities for the Polish farms, with some farms having up to 3.5 livestock units per ha (1 livestock unit= 1LU corresponds to 100 kg N spread in the form of livestock manure). However, 85% of the farm population have a livestock density below 1.5 LU/ha, and the average livestock density is 0.7 LU/ha. In contrast, 95% of the Danish farms had below 1.7 LU/ha, corresponding to the maximum permitted livestock density according to Danish environmental legislation. However, the average farm in the Danish landscape has a higher livestock density (1.0 LU/ha) than in the Polish landscape. These characteristics may explain, why the Polish landscape has the same average N-surplus as the Danish landscape even though the average livestock density is lower: As illustrated in figure 5, and in line with the findings of Dalgaard et al. 2002 and Kjeldsen et al. 2006, the non-linear relation between livestock density and N-surplus may explain why the larger variation in livestock densities in the Polish landscape leads to a relatively high average N-surplus compared to the livestock density (because the even few very livestock dense farms contribute relatively more per livestock unit to the overall N-surplus, than farms with a lower livestock density). As discussed below, the same argument may count for the individual components of the N-surplus (i.e. ammonia loss, leaching, denitrification or soil-N change), if the component shows the same non-linear relation between livestock density and N-loss. Below we will discuss some potential mechanisms explaining these non-linear effects, namely differences in management practices among farms and among landscapes.

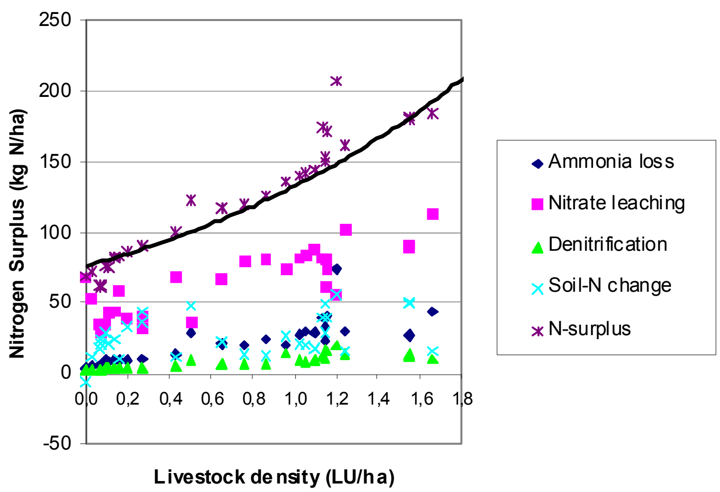

Figure 5. N-surpluses and the distribution into ammonia losses, nitrates leaching, denitrification and soil-N changes for farms in the Danish landscape, simulated with the Farm-N model for the year 2002. The curve shows the exponential function fitted for livestock density versus N-surplus ($y= 76*e^{0,56x}$, R^2=0.92), apparently mainly caused by non-linear functions in relation to ammonia losses and nitrate leaching to be investigated further in future studies.

3.2 Effects of management practices and timing

To illustrate the effect of different management practices and timing of farm operations, we used the FASSET model to simulate two identical pig farms with the different management practices and weather conditions in the Danish and the German MEA-scope study landscape (Table 1).

Table 1. Crop rotation and fertilisation with Nitrogen in the form of organic (slurry) and inorganic (ammonium-nitrate) fertilisers at a model pig bacon farm on sandy soil in Viborg, Denmark and Brandenburg, Germany.

		Viborg, Denmark		Brandenburg, Germany	
Crop Rotation Unit	Field area (ha)	Fertilisation Organic ($kg\ N\ ha^{-1}$)	Fertilisation Inorganic ($kg\ N\ ha^{-1}$)	Fertilisation Organic ($kg\ N\ ha^{-1}$)	Fertilisation Inorganic ($kg\ N\ ha^{-1}$)
Set aside	42	0	0	0	0
Set aside	42	0	0	0	0
Winter wheat	42	150	54	150	72
Winter rape	42	150	59	150	77
Winter wheat	42	150	27	150	45
Winter wheat	42	150	54	150	72
Winter barley	42	118	63	118	79
Winter rye	42	102	45	102	58
Winter rape	42	150	59	150	77
Winter wheat	42	150	27	150	45
Winter wheat	42	150	54	150	72
Winter barley	42	118	63	118	79
Set aside	42	0	0	0	0
Total	546	58283	21009	58283	28378

As indicated, it is assumed that we have the same amount of manure and the same manure fertilisation to the same crops under the two conditions. However, like the case of Figure 4, the Danish landscape has more strict regulations on the maximum allowed N fertilisation, and the additional inorganic fertiliser spread is significantly lower in the Danish compared to the German situation. Moreover, in the Danish situation all the manure is spread in spring, whereas most of the manure in the German landscape is spread in autumn, leading to significant differences in the ammonia losses simulated (Figure 6).

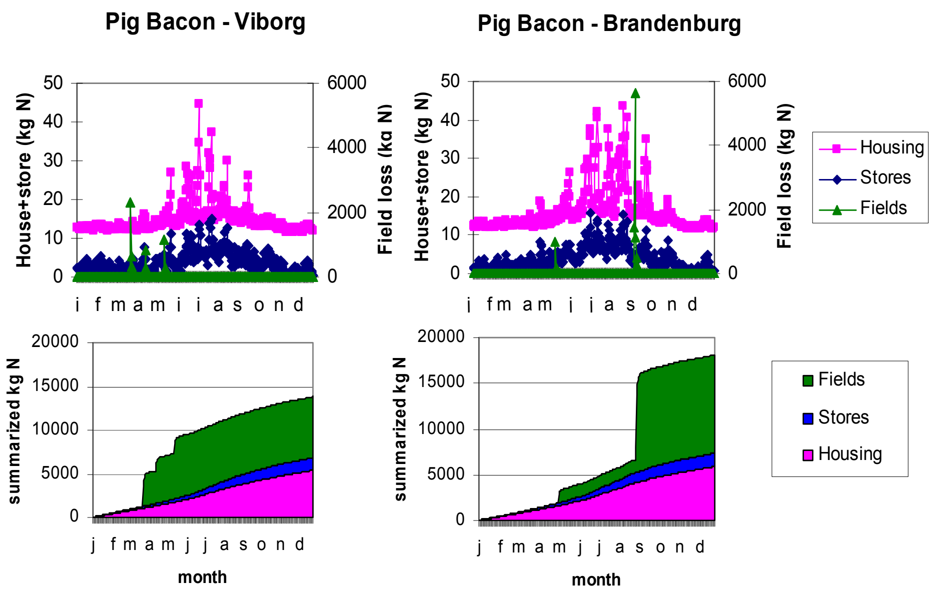

Figure 6. Ammonia emissions simulated with the FASSET model for two identical farms with the current management practices in the Viborg landscape (Denmark) and the Brandenburg landscape (Germany). The top graphs show average values based on the ten years of weather data from Figure 2, and the bottom graphs show the summarized N-losses, which after 12 months are significantly higher in Brandenburg compared to Viborg.

4. CONCLUSIONS AND RECOMMENDATIONS

The results presented, show examples on farm nitrogen surpluses from different European landscapes, and the models used to simulate farm ecosystem services in the form of production, and the related effects on nitrogen cycling from of ammonia emission, nitrate leaching, denitrification and soil-N pooling in agricultural landscapes.

In a case study, comparing results from a Polish and a Danish landscape with similar land use, it is demonstrated how the variation in farm livestock density effects the average N-surplus. Due to non-linearities between livestock density and N-losses per hectare, it is hypotheisised that a large variation in farm livestock density may significantly increase the N-surplus and the related N-losses, and that such effect can be explored with farm model tools like the Farm-N model implemented in the present study. This has implications for the relations between provisioning ecosystem services (farm production), supporting services (nutrient and greenhouse gas cycling and dispersal), and regulating services (effects on water and climate), as discussed in the Millennium Ecosystem Assessment (2005).

Management practice and the timing of farm operations also affect the level of farm N-losses, and can be modelled by the Farm Assessment Tool (FASSET). This was exemplified by a study of the temporal patterns in ammonia losses from the same pig farm simulated for a German and a Danish study landscape with different management practices. The results show that the spring time manure spreading in the Danish landscape leads to a lower ammonia emission than the autumn spreading in the German landscape, and that the fertilisation timing thereby may have significant effects on the N-losses.

Based on these results we must recommend taking into account the effect of between farm variation when modelling nitrogen losses and the related greenhouse gas emissions at the landscape level, and assessing the costs and risks of ecosystems services provided by agriculture (Hanson et al. 2008). The distribution of livestock and livestock manure, and the management and timing of manure spreading are important factors to include when dealing with options to mitigate nitrogen losses to the environment, and must be taken into account in the ongoing development of a whole landscape simulation tool (NitroScape), designed to model nitrogen (N) and carbon (C) fluxes and the related emissions of greenhouse gasses.

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