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# Modeling nitrous oxide emissions from organic and conventional cereal-based cropping systems under different management, soil and climate factors

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ABSTRACT

Mitigation of greenhouse gas emissions from agriculture should be assessed across cropping systems and agroclimatic regions. In this study, we investigate the ability of the FASSET model to analyze differences in the magnitude of $N_2O$ emissions due to soil, climate and management factors in cereal-based cropping systems. Forage maize was grown in a conventional dairy system at Mabegondo (NW Spain) and wheat and barley in organic and conventional crop rotations at Foulum (NW Denmark). These two European sites represent agricultural areas with high and low to moderate emission levels, respectively. Field trials included plots with and without catch crops that were fertilized with either mineral N fertilizer, cattle slurry, pig slurry or digested manure. Non-fertilized treatments were also included. Measurements of $N_2O$ fluxes during the growing cycle of all the crops at both sites were performed with the static chamber method with more frequent measurements post-fertilization and biweekly measurements when high fluxes were not expected. All cropping systems were simulated with the FASSET version 2.5 simulation model. Cumulative soil seasonal $N_2O$ emissions were about ten-fold higher at Mabegondo than at Foulum when averaged across systems and treatments (8.99 and 0.71 kg $N_2O$-N $ha^{-1}$, respectively). The average simulated cumulative soil $N_2O$ emissions were 9.03 and 1.71 kg $N_2O$-N $ha^{-1}$ at Mabegondo and at Foulum, respectively. Fertilization, catch crops and cropping systems had lower influence on the seasonal soil $N_2O$ fluxes than the environmental factors. Overall, in its current version FASSET reproduced the effects of the different factors investigated on the cumulative seasonal soil $N_2O$ emissions but temporally it overestimated emissions from nitrification and denitrification on particular days when soil operations, ploughing or fertilization, took place. The errors associated with simulated daily soil $N_2O$ fluxes increased with the magnitude of the emissions. For resolving causes of differences in simulated and measured fluxes more intensive and temporally detailed measurements of $N_2O$ fluxes and soil C and N dynamics would be needed.



## 1. Introduction

Agricultural practices such as soil tillage, nitrogen (N) fertilization and residue management, may significantly influence soil nitrous oxide ($N_2O$) emissions during and after the crop growing season (Mutegi et al., 2010; Van Groenigen et al., 2010; Brozyna et al., 2013). Moreover, soil properties and climatic factors affect the processes responsible for both $N_2O$ production and emission. In order to mitigate climate change and the associated impacts, it is particularly important to identify and adopt crop management practices that most effectively reduce greenhouse gas (GHG) emissions from agricultural soils in cropping systems covering major areas within each agro-climatic region as well as from cropping systems that, due to climate and/or soil factors, have a high risk of GHG emissions (IPCC, 2014).

Lesschen et al. (2011) proposed a correction to the default IPCC emission factors (EF) that considered management and environmental variables such as precipitation and soil type for different

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regions across Europe. Also Li et al. (2001), based on predictions from an agro-ecosystem simulation model, found that soil organic matter (SOM) content was the main driver of variability in GHG emissions from fertilizer applications in China. It is therefore, essential to have reliable tools that can aid understanding and quantification of differences in $N_2O$ emissions among different N management options under specific agro-climatic regions (Butterbach-Bahl et al., 2013). Such tools would allow us to identify those measures that have the highest N use efficiency, provide better N cycling and reduce environmental impacts from nitrate leaching to groundwater and surface water and climate impacts from $N_2O$ emissions.

The ability of biogeochemical models to integrate complex processes controlling $N_2O$ production, consumption and transport make them important tools for evaluating $N_2O$ emissions from different cropping systems and assessing emissions from agricultural systems at both regional and global scales. Examples of the use of process-based models to assess $N_2O$ emissions from different cropping systems are Li et al. (2004) with DNDC, Del Grosso et al. (2005) with DAYCENT, Chatskikh et al. (2005) with FASSET and Metay et al. (2011) with NOE.

Chirinda et al. (2011) tested the FASSET model against data from different organic arable farming systems and concluded that the model was capable of simulating trends of seasonal soil $N_2O$ emissions, but it showed deficiencies in modeling SOM turnover that affected the predictions of heterotrophic soil respiration in systems that included catch crops. A reformulation of the function used in the model to represent soil tillage has been implemented in FASSET 2.5. This allows for a more realistic distribution of crop residues in the soil profile after soil operations (tillage and harrowing) to simulate a non-homogenous distribution of crop residues.

In our study, we investigate the ability of FASSET 2.5 to analyze differences in the magnitude of $N_2O$ emissions due to (a) management factors, including N management in organic and conventional cropping systems with and without catch crops and (b) environmental factors (soil and climate) in two cereal-based cropping systems representing major agricultural areas in each region. Forage maize in the Atlantic North Spain (Galicia, Asturias, Cantabria and Basque Country) represents 77% of the area dedicated to this crop in the country and 94% if only rainfed forage maize is considered (MAGRAMA, 2012). Winter wheat represents about 44% of the total cereal area in Denmark and together with spring barley they constitute about 30% of the area under organic farming (Plantedirektoratet, 2009). According to Lesschen et al. (2011), the cereal-based cropping systems investigated in this study were located in an area with high (Galicia, Spain) and low to moderate (Central Jutland, Denmark) risk of soil $N_2O$ emissions.

## 2. Materials and methods

### 2.1. Forage maize experiments at Mabegondo (Galicia, Spain)

Field trials with forage maize (*Zea mays* L.) in a conventional dairy system were performed for two growing seasons (2009 and 2010) on a silty loam soil at Mabegondo (Galicia) in North West Spain. The site has a South Atlantic climate (Iglesias et al., 2009) with an annual average temperature and precipitation of 13.1 °C and 1101 mm, respectively, for the period 1998–2007. The daily pattern of these two climatic variables during the years studied (Apr 09–Oct10) is shown in Fig. 1. Main site and crop management details are described in Table 1. The maize crop in 2009 was preceded by a fallow period in autumn-winter after a crop sequence of triticale-pea mixture as winter crop on the previous year and maize in summer. In 2010, maize was preceded by a five-year grazed grassland which was discontinued in spring, two months before sowing of the maize crop. Crop residues were always returned to the soil and managed with conventional tillage. Different fertilizers were tested: mineral fertilizer, cattle slurry and pig slurry. Also, a non-fertilized treatment was used as control. The target application rate for the organic fertilizers was 200 kg N ha$^{-1}$ applied 3–4 days before sowing. The same amount was applied to the mineral fertilizer treatment split in two applications: N–P–K 15-15-15 (7% nitrate-N; 7% ammonium-N) at a rate of 125 kg N ha$^{-1}$ at sowing and urea 46% at a rate of 75 kg N ha$^{-1}$ for top dressing when the plant was 40 cm tall.

Nitrous oxide fluxes were measured using the closed chamber technique (Ryden and Rolston, 1983). Two chambers per plot (i.e., six chambers per treatment) were placed between rows and left in the same position during the experiment. After the N applications, gas samples were taken three or five times a week for analysis of $N_2O$. $N_2O$ fluxes for dates between samplings were calculated using the trapezoidal method (Cardenas et al., 2010; Louro et al., 2013). Cumulative $N_2O$ fluxes were calculated by summing daily flux rates. Coinciding with gas samplings, soil samples at 10 cm depth were collected for the analysis of mineral N contents ($NH_4$-N and $NO_3$-N) and soil moisture. Soil $NH_4$-N and $NO_3$-N were determined colorimetrically after extracting 100 g of fresh soil with 200 ml 1 M KCl. Soil moisture content was determined gravimetrically after oven drying the samples at 105 °C for 24 h. Porosity was calculated from bulk density (Bd) in each site by assuming a particle density of 2.65 Mg m$^{-3}$. Water filled pore space (WFPS) was calculated by dividing the soil moisture content and Bd by the porosity.

### 2.2. Winter wheat and spring barley in arable cropping systems at Foulum (Central Jutland, Denmark)

Winter wheat (*Triticum aestivum* L.) and spring barley (*Hordeum vulgare* L.) were grown in different organic and conventional arable crop rotations in 2008 and 2009 on a loamy sand soil at Foulum (Denmark) in Central Jutland. Main soil characteristics, average climate and crop management details are reported in Table 1. Several combinations of catch crop, fertilizer and manure management practices were selected for our study. These treatments included the application of fresh or digested pig slurry, mineral fertilizers and unfertilized control plots, in systems with or without catch crops. Fertilization was performed in spring for all crops (end of March–mid-June). In the spring barley, grass-clover was undersown in spring and in the following year the grass-clover was cut and removed in the manure treatment, whereas cuttings were left on the soil in the treatment without fertilizer application. A detailed description of these treatments can be found in Chirinda et al. (2010) and Brozyna et al. (2013). The cereal crops were sown at a depth of 2–4 cm and at a row distance of 12–12.5 cm. Weeds were controlled with tine harrowing in the organic systems and with chemical spraying in the conventional ones.

Measurements of soil $N_2O$ fluxes during the growing cycle of all the crops and during the non-growing period were performed using static chambers described by Chirinda et al. (2010), and with a frequency from every two weeks to few days following fertilization events. Each study plot had two replicate chambers (two plots per treatment). Cumulative fluxes in each treatment were computed by linear interpolation between measurement dates. Every other week, concurrent with gas samplings, soil samples were collected in all the plots to monitor $NO_3$-N and $NH_4$-N contents (0–30 cm depths). Soil mineral N in the collected samples was determined according to Keeney and Nelson (1982).

### 2.3. Simulating $N_2O$ emissions with FASSET 2.5: model description and equations

The dynamic crop simulation model Farm ASSEsment Tool (FASSET) (Olesen et al., 2002; Berntsen et al., 2003) is a deterministic