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High-resolution inventory of NO emissions from agricultural soils over the Ile-de-France region

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The use of an agro-ecosystem model at regional scale makes it possible to map the emissions of nitric oxide from arable soils at a resolution compatible with tropospheric ozone models.

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ABSTRACT

Arable soils are a significant source of nitric oxide (NO), a precursor of tropospheric ozone, and thereby contribute to ozone pollution. However, their actual impact on ozone formation is strongly related to their spatial and temporal emission patterns, which warrant high-resolution estimates.

Here, we combined an agro-ecosystem model and geo-referenced databases to map these sources over the 12 000 km^2 administrative region surrounding Paris, France, with a kilometric level resolution. The six most frequent arable crop species were simulated, with emission rates ranging from 1.4 kg N–NO ha^{-1} yr^{-1} to 11.1 kg N–NO ha^{-1} yr^{-1}. The overall emission factor for fertilizer-derived NO emissions was 1.7%, while background emissions contributed half of the total NO efflux. Emissions were strongly seasonal, being highest in spring due to fertilizer inputs. They were mostly sensitive to soil type, crops' growing season and fertilizer N rates.

1. Introduction

Although agricultural soils have been recognized as a significant source of nitric oxide (NO), their contribution is still uncertain, ranging from 10% to 23% of the global NO_x budget (Davidson and Kingerlee, 1997; Delmas et al., 1997), with a 15% share in Europe (Simpson et al., 1999). They may play a significant role in the tropospheric chemistry of ozone (O_3) in rural areas, where NO_x emissions from combustion sources are relatively small. This also holds in the vicinity of urban areas, where arable soils are tightly intertwined with other sources of ozone precursors such as road traffic, forests, or residential and industrial areas. Photochemical processes are highly dependent on the spatial and temporal patterns of natural and anthropogenic sources of ozone precursors, and their simulation warrants high-resolution estimates of these sources in both space and time.

In arable soils, NO is produced through the microbial processes of nitrification and denitrification. Nitrification is an oxidation of NH_4^+ to NO_2^- and NO_3^-, which requires the availability of molecular oxygen, while denitrification is an anaerobic reduction of NO_3^- to gaseous forms of N (N_2O and N_2). The nitrification pathway predominates in temperate zones (Laville et al., 2005), accounting for 60–90% of total NO emissions (Godde and Conrad, 2000), and is regulated by environmental and agronomic factors including cropping practices, soil characteristics and climate. Crop management influences the dynamics of soil ammonium content, which is a substrate for nitrification, while the latter influence soil temperature and water-filled pore space (WFPS), which is a proximate for soil oxygen concentration and a driver for gaseous diffusivity (Linn and Doran, 1984).

Given the complexity of the microbial processes driving the exchanges of reactive N (Nr) between soils and the atmosphere, estimates of biogenic sources remain highly uncertain at regional to global scales. National inventories of Nr sources from ecosystems currently mostly rely on sets of emission factors derived from field-scale experiments, assuming Nr emissions to be a fixed fraction of Nr inputs or dependent solely on soil temperature. Such is the case

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Table 1
Areas and management practices for the 6 dominant crop types and fallow soils in the Ile de France region. Dates are given as days of year (year).

Crop type	Area (ha)	Management practices			
		Sowing	Fertilizer application		
		Date	Date	Rate[a]	Form
Maize (*Zea mays* L.)	43 144	107(2001)	115 (2001)	140	UAN[b]
Wheat (*Triticum aestivum* L.)	256 974	295 (2000)	63 (2001)	60	UAN[b]
			93 (2001)	100	AN[c]
Barley (*Hordeum vulgare* L.)	60 162	289 (2000)	54 (2001)	60	UAN
			92 (2001)	100	UAN
Rapeseed (*Brassica napus* L.)	52 015	251 (2000)	29 (2001)	60	AN
			51 (2001)	120	AN
Pea (*Pisum sativum* L.)	32 278	98 (2001)	none		
Sugarbeet (*Beta vulgaris* L.)	41 727	112 (2001)	29 (2001)	40	AN
			58 (2001)	89	AN
Fallow soils[d]	38 711	240 (2000)	none		

[a] Unit: kg N ha^{-1}.
[b] UAN: nitrogen solution (50% urea and 50% ammonium-nitrate, in liquid form).
[c] AN: ammonium-nitrate.
[d] Simulated as a mustard catch crop, ploughed in date on day of year 182 (2001).

for the widely-used EMEP/CORINAIR methodology (Skiba et al., 2001; Stohl et al., 1996).

In recent years, biophysical ecosystem models have been used to develop more realistic, spatially-explicit inventories of gaseous Nr emissions from soils, based on specific geographical information systems (GIS) and databases (Butterbach-Bahl et al., 2001, 2004, 2009; Li et al., 2004; Gabrielle et al., 2006b). Such models make it possible to simulate the temporal and spatial dynamics of emissions, typically on a daily basis. Geo-referenced databases are used to localize the sources of Nr emissions, as well as to map model inputs, including soil characteristics, land-use and management, and weather data. They are used in a wide range of scientific fields, including climatology and climate change studies, agriculture, forestry and ecology (Chapman and Thornes, 2003). For instance, the DNDC and PnET-N-DNDC models were used to develop regional inventories NO and N_2O emissions from cropland and forests in various parts of the world (Butterbach-Bahl et al., 2001, 2004; Li et al., 2004; Kiese et al., 2004). In these studies, the spatial generalization at the regional scale was based on plot-scale simulations at the nodes of a regular grid involving particular sets of crop management, soil, and climate data. Spatial interpolation of the grid points to cover the entire domain was either not considered (implying the points were representative of the whole grid cell), or done using kriging techniques. The density of the grid points (with a grid resolution of 4–20 km) was generally too low to adequately capture the short-range variations in agricultural field properties, which are in the 0.1–1 km range.

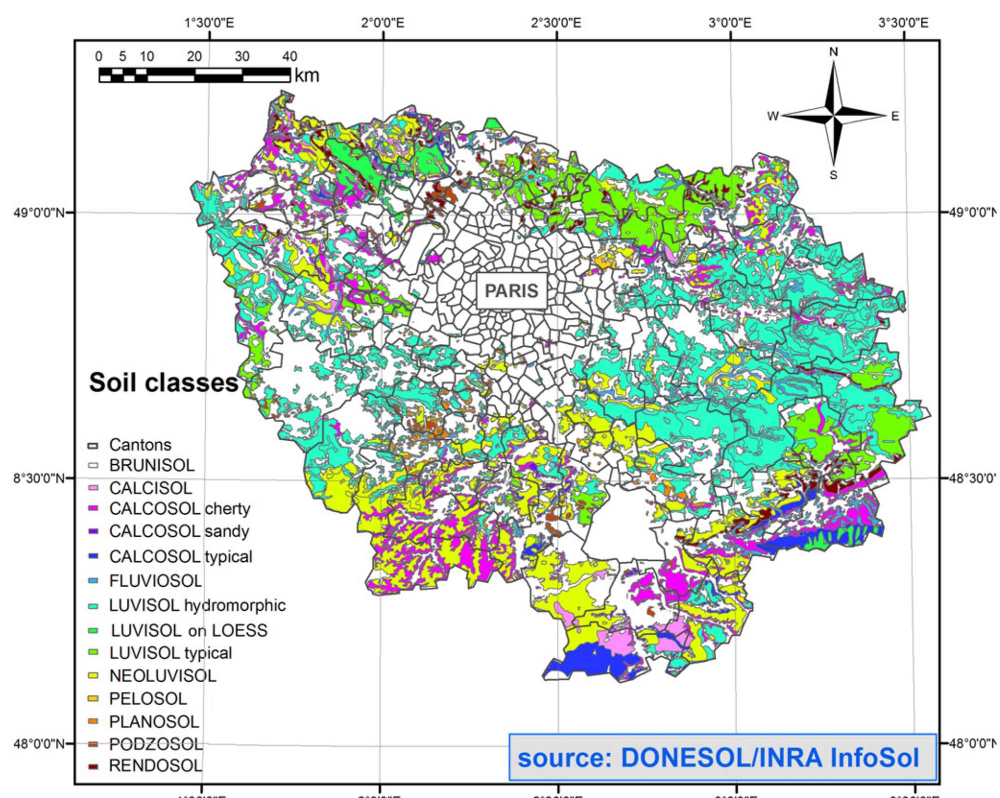

Fig. 1. Soil map units as overlaid with administrative county limits and the presence of arable crops in the Ile de France region.