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Assessment of methane and nitrous oxide fluxes in rural landscapes

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ABSTRACT

We estimated CH_4 and N_2O emissions from the main land-use types in rural landscapes using data from the literature (950 study sites/experiments from the temperate and boreal zone published from 1980 to 2009 in 165 scientific papers indexed by the ISI Web of Science) and assessed the emission potential of CH_4 and N_2O from rural landscapes in Estonia. According to this analysis, natural peatlands and marshes appeared to be the most important CH_4 emitters, whereas N_2O is emitted mainly from drained peatlands and marshes, set aside areas, conventional arable lands, fertilized grasslands, and coniferous and mixed forests – all on hydromorphic soils. The estimated median value of annual CH_4-C and N_2O-N fluxes for Estonian rural landscapes are 25,519 and 11,050 t respectively. CH_4 consumption makes up 13.2% of the emission. The largest CH_4 emitters are peatlands (17,746 t CH_4-C year^{-1}; 60%), whereas coniferous and mixed forests on hydromorphic soils with altered hydrologic regime are responsible for the bulk (51%) of N_2O fluxes. The Global Warming Potential (GWP) of Estonian rural land-use types (42,685 km^2) from potential CH_4 and N_2O fluxes is 5.99 million t of CO_2 equivalents, of which N_2O is responsible for 86%. Several measures for the further mitigation of greenhouse gas emission from rural landscapes are proposed.

1. Introduction

The regulation of material fluxes and energy flows is one of the most important functions of rural landscapes (De Groot, 2006). The emission of greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) is a key component of global biogeochemical cycles (Kreileman and Bouwman, 1994), whereas interactions between these gases and its effects are largely unknown (Liu and Greaver, 2009). Although the emission of CH_4 and N_2O from various land-use types is a well-studied environmental phenomenon (Martikainen et al., 1993; Le Mer and Roger, 2001; Jungkunst and Fiedler, 2007), there is a need for estimations of fluxes at landscape and regional level that could be useful for regional and local authorities to develop measures and land-use policy and landscape management practices for the minimization of land-use-based GHG emissions. Conflicting reactions of GHG fluxes on the changes of environmental factors and land-use change makes the spatial planning and landscape management tasks challenging.

Attempts to estimate and model GHG fluxes have been made at many scales, from micro-site or field level (Alm et al., 2007 for carbon (C) balance of fen micro-sites; Conen et al., 2000 for N_2O fluxes from soils) and ecosystem level (Aurela et al., 2002 for CO_2 and CH_4 balance of a fen; Pörtl et al., 2007 for N_2O fluxes of a forest) to catchment level (Flessa et al., 2008 for CH_4 fluxes of a catchment in Siberian tundra; Worrall et al., 2009 for C budget of a peat-covered catchment; Oehler et al., 2009 for denitrification), landscape level (Pennock and Corré, 2001 for N_2O emission related to landform segments; Bareth et al., 2001 for N_2O emission in an agricultural landscape; Werner et al., 2003 for CH_4 fluxes of a temperate/boreal lowland area, based on infrared investigations from a tall tower; Heikkinen et al., 2004 for C balance of tundra landscapes; Sommer et al., 2004 for CH_4 fluxes of an agricultural landscape; Pattey et al., 2006 for CH_4 and N_2O fluxes from a boreal forest landscape using micrometeorological techniques; Nol et al., 2008 for N_2O fluxes of a fen-meadow landscape; Phillips and Beeri, 2008 for CO_2, CH_4, and N_2O fluxes of an agricultural wetland landscape), to regional scale (Corré et al., 1999 for N_2O emission of a grassland-forest region; Sozanska et al., 2002 for N_2O emissions from Great Britain; Lilly et al., 2003 for N_2O emissions in Scotland; Li et al., 2004 for CO_2, CH_4 and N_2O emissions from rice-based production systems) and continental scale (Saarnio et al., 2009 for CH_4 emission from wetlands

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and watercourses in Europe). In terms of the scale and methods, our GIS-based attempt is similar to those presented in Sozanska et al. (2002), Lilly et al. (2003), Sommer et al. (2004) and Nol et al. (2008).

The mitigation of GHG emission is one of the key issues in adaptation to climate change (IPCC, 2007). Sustainable landscape planning can regulate the optimal performance of ecosystems services, including GHG mitigation of both rural (Bailey et al., 2006) and urban areas (Gill et al., 2008). Land-use changes play a key role in the regulation of CO_2 fluxes and soil C stocks in landscapes (Guo and Gifford, 2002; Wise et al., 2009). Old-growth forests (Ciais et al., 2008; Luyssaert et al., 2008) and undisturbed wetlands (Bridgham et al., 2006) are the main carbon sinks worldwide, and their conversion to agricultural land will increase CO_2 fluxes (Guo and Gifford, 2002). Agroforestry and the reforestation of abandoned lands (Paustian et al., 1997; Albrecht and Kandji, 2003) and sustainable management practices such as the use of green manures (Paustian et al., 1997), conversation tillage (Subak, 2000), and no-till farming (Paustian et al., 1997; Johnson et al., 2007) have been reported as measures for the preservation of soil C stocks. Following the principles of sustainable land management, agricultural soils can play an important role as C sinks (Lal, 2004, 2008). The cultivation of bioenergy crops as a new element in GHG mitigation and C sequestration (Smith et al., 2000; Garcia-Quijano et al., 2005) needs more comprehensive analysis because of potential conflicts with other ecosystem services such as biodiversity and landscape diversity functions (Haughton et al., 2009; Wise et al., 2009). In addition, short-rotation energy forestry could cancel out the benefits of C storage over recent decades (Ciais et al., 2008). On the other hand, when one also considers the mitigation of CH_4 and N_2O fluxes, the cultivation of bioenergy crops (Regina et al., 2009), the establishment of hedges, shelterbelts (Falloon et al., 2004) and organic agriculture (Johnson et al., 2007) seem to be the most beneficial management practices. Especially on organic soils, the cultivation of perennial grass for bioenergy is found to be a promising measure for the minimizing of GHG emissions (Hyvönen et al., 2009; Shurpali et al., 2009).

All these mitigation methods and spatial planning approach are useful if there is an adequate estimation on GHG emissions from the considered area. This kind of estimation was the general aim of this paper. The main objectives of this study are (1) to assess and analyse CH_4 and N_2O fluxes from the main land-use types of rural landscapes using data from the literature, and, based on that information (2) to estimate the emission potential of CH_4 and N_2O from rural landscapes in Estonia.

2. Materials and methods

2.1. Literature analysis

We analysed data from about 950 study sites/experiments from the temperate and boreal zone of the Northern Hemisphere published from the early 1980s to 2008 in 165 scientific papers indexed by the ISI Web of Science. Only data from investigations covering at least a one-year period and analyses that permitted the creation of an annual estimate (estimation of fluxes from both warm and cold periods) have been taken into account. All papers considering CH_4 and N_2O fluxes from arable land, grasslands, abandoned (set aside) agricultural land, forests, peatlands and freshwater marshes have been taken into account. The database made it possible to distinguish between the following land-use types: (1) intensively used arable land (conventional farms and areas with high rates of use of mineral fertilizers); (2) less intensively used arable land (organic agriculture and minimally fertilized conventional fields); (3) intensively managed (fertilized) grasslands; (4) less intensively managed (mostly unfertilized) grasslands; (5) abandoned (set aside) agricultural land; (6) deciduous forests; (7) coniferous forests; (8) mixed deciduous-coniferous forests; (9) fens and transitional fens; (10) raised/oligotrophic bogs and woodland bogs; (11) freshwater marshes; (12) various peatlands (drained and restored peatlands, peat production areas). Land-use types 1–8 were analysed for both automorphic soils (a wide spectrum of Luvisols, Planosols, Leptosols, Cambisols, Podzols) and hydromorhic soils (Gleysols and Histosols). As concerns peatlands and marshes (types 9–11), both undisturbed and drained variants have been taken into account. In the literature, some data were found concerning moorlands and blanket bogs, but due to the insignificant presence of their analogues (moors and heathlands) in Estonia, this group has been excluded. Likewise, all anthropogenic areas (towns, settlements, roads, industrial territories, quarries), lakes and rivers have been excluded from our study.

2.2. Digital maps

The analysis of area-based greenhouse gas emission from the non-urban landscape in Estonia is based on the Estonian Soil map, the map of Estonian drainage systems, and the Corine Land Cover Map of Estonia. The nominal scale of the soil map is 1:200,000, the minimum size of mapping units is 2 ha, the average 419 ha and the maximum size 17,201 ha. The digital soil map has 54 soil type classes, and soil texture data is given separately for topsoil and deeper layer(s).

The digital map of Estonian drainage systems has a nominal scale of 1:10,000, with the smallest mapped drainage system having an area of 0.5 ha, the average area of drainage systems is 221 ha, and the largest drainage unit has an area of 4271 ha. Due to the insufficient spatial accuracy of the drainage map for our GIS analysis, we could only partly (for fens and transitional bogs, some of them afforested) separate the drained and non-drained areas when calculating the GHG fluxes. Thus the influence of water table changes on GHG flux is embedded in the summary values for different land-use types.

Land-use and land cover information was derived from the digital map of Corine Land Cover as of the year 2000. The nominal scale is 1:100,000, the smallest mapping unit corresponds to 25 ha, the average size of land cover units is 127 ha, and the largest land cover unit has a size of 25,805 ha.

2.3. GIS analysis

GIS map algebra was used to estimate greenhouse gas emissions from non-urban landscapes in Estonia. The geometric intersection of the soil map with the digital map of Estonian drainage systems was performed to determine automorphic and hydromorphic soils. This output map was overlaid and intersected by the Corine Land Cover map to define soil types for different land-use units.

To relate Estonia's Corine land cover units to land-use classes established on the basis of a review of the literature and statistical analysis, we used the transition matrix presented in Table 1.

In general, our methodology follows the Tier 1 and Tier 2 protocols for the estimation and national reporting of GHG fluxes (Eggleston et al., 2006; IPCC, 2007).

2.4. Statistical analysis

All of the data were analysed for normality of distribution using the Lilliefors and Shapiro–Wilk tests and the programme STATISTICA 7.0. According to the non-normal distribution of all datasets, the Mann–Whitney *U*-test was used to test significance between the CH_4 and the N_2O fluxes from different land-use and soil types. The level of significance of $\alpha = 0.05$ was considered in all cases.