Agriculture, Ecosystems and Environment 136 (2010) 199–208

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Emissions of nitrous oxide from arable organic and conventional cropping systems on two soil types

Ngonidzashe Chirinda [a,c,*], Mette S. Carter [b], Kristian R. Albert [b], Per Ambus [b], Jørgen E. Olesen [a], John R. Porter [c], Søren O. Petersen [a]

[a] Dept. of Agroecology and Environment, Faculty of Agricultural Sciences, Aarhus University, P.O. Box 50, DK-8830 Tjele, Denmark
[b] Risø National Laboratory for Sustainable Energy, Technical University of Denmark, P.O. Box 49, 4000 Roskilde, Denmark
[c] Faculty of Life Sciences, University of Copenhagen, Højbakkegaard Alle 9, 2630 Taastrup, Denmark

ARTICLE INFO

Article history:
Received 10 May 2009
Received in revised form 11 September 2009
Accepted 13 November 2009
Available online 16 December 2009

Keywords:
Catch crop
Crop rotation
Greenhouse gas
Mineral fertilizer
N_2-fixation
Pig slurry
Winter wheat

ABSTRACT

Conventional cropping systems rely on targeted short-term fertility management, whereas organic systems depend, in part, on long-term increase in soil fertility as determined by crop rotation and management. Such differences influence soil nitrogen (N) cycling and availability through the year. The main objective of this study was to compare nitrous oxide (N_2O) emissions from soil under winter wheat (*Triticum aestivum* L.) within three organic and one conventional cropping system that differed in type of fertilizer, presence of catch crops and proportion of N_2-fixing crops. The study was replicated in two identical long-term crop rotation experiments on sandy loam soils under different climatic conditions in Denmark (Flakkebjerg—eastern Denmark and Foulum—western Denmark). The conventional rotation received 165–170 kg N ha^{-1} in the form of NH_4NO_3, while the organic rotations received 100–110 kg N ha^{-1} as pig slurry. For at least 11 months, as from September 2007, static chambers were used to measure N_2O emissions at least twice every calendar month. Mean daily N_2O emissions across the year ranged from 172 to 438 μg N m^{-2} d^{-1} at Flakkebjerg, and from 173 to 250 μg N m^{-2} d^{-1} at Foulum. A multiple linear regression analysis showed inter-seasonal variations in emissions ($P < 0.001$), but annual N_2O emissions from organic and conventional systems were not significantly different despite the lower N input in organic rotations. The annual emissions ranged from 54 to 137 mg N m^{-2}, which corresponded to 0.5–0.8% of the N applied in manure or mineral fertilizer. Selected soil attributes were monitored to support the interpretation of N_2O emission patterns. A second multiple linear regression analysis with potential drivers of N_2O emissions showed a negative response to soil temperature ($P = 0.008$) and percent water-filled pore space (WFPS) ($P = 0.052$) at Foulum. However, there were positive interactions of both factors with NO_3-N, i.e., high N_2O emissions occurred during periods when high soil nitrate levels coincided with high soil temperature ($P = 0.016$) or high soil water content ($P = 0.056$). A positive effect ($P = 0.03$) of soil temperature was identified at Flakkebjerg, but the number of soil samplings was limited. Effects of cropping system on N_2O emissions were not observed.

1. Introduction

Agricultural soils contribute approximately 60% to total anthropogenic emissions of nitrous oxide (N_2O) (Kroeze et al., 1999), a potent greenhouse gas that is also involved in the destruction of stratospheric ozone (Cicerone, 1987). As an intermediate in microbially mediated nitrification and denitrification processes, N_2O is also a pathway of soil nitrogen (N) loss (Farquharson and Baldock, 2008). Input of N from organic or inorganic sources, such as crop residues, livestock manure and synthetic fertilizers, enhance biogenic N_2O emissions from agricultural soils (Mosier et al., 1998). However, the magnitude and distribution of N_2O emissions from arable soils depend on many factors; the type and management of N fertilizer (Hao et al., 2001; Bouwman et al., 2002a), preceding crop and residue management (Huang et al., 2004; Chen et al., 2008), and prevailing climatic conditions and soil properties, especially soil aeration status, temperature and carbon availability (Novoa and Tejeda, 2006; Ruser et al., 2006). Hence, cropping systems based on different fertilizer types, soil types and crop management regimes could influence N_2O emissions differently.

Conventional cropping systems rely mainly on inorganic fertilizers and are characterized by short-term fertility management. The large availability of mineral N in the soil may induce

* Corresponding author at: Department of Agroecology and Environment, Faculty of Agricultural Sciences, Aarhus University, P.O. Box 50, DK-8830 Tjele, Denmark. Tel.: +45 8999 1081/1900; fax: +45 8999 1919.
E-mail address: Ngonidzashe.Chirinda@agrsci.dk (N. Chirinda).

0167-8809/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2009.11.012

high N_2O emissions (Bouwman et al., 2002b), depending on soil conditions. In contrast, organic systems use manure, if available, and depend more on a long-term increase in soil fertility, biodiversity and internal N cycling (Watson et al., 2002). Manure has a lower availability of mineral N, but contains N in organic matter that will decompose in the soil. Lack of synchrony between N release and crop demand can stimulate N_2O emissions from systems relying on organic fertilizers (Bouwman, 1996). The long-term influence of fertilizer type on N_2O emissions remains unclear (Snyder et al., 2007).

Manure management strategy significantly affects soil N transformations, which complicates the estimation of annual N_2O fluxes for manure-based systems (Akiyama and Tsuruta, 2003). For instance, anaerobic digestion of manure prior to field application can decrease N_2O emissions from surface-applied manure compared to untreated or separated manure (Chantigny et al., 2009), although this effect may depend on soil type and climatic conditions (Thomsen et al., 2010).

Inclusion of leguminous crops within crop rotations reduces the need for external fertilizer N inputs because legumes assemble atmospheric N_2 via biological N fixation. This N source could potentially lead to increased N_2O emissions from the crop. Rochette and Janzen (2005) proposed that N_2O from leguminous crops was derived mainly from root exudates and crop residue decomposition; in accordance with this Carter and Ambus (2006) found, in a study with grass-clover mixtures grown in a $^{15}N_2$-enriched atmosphere, that only 2% of the total N_2O emitted from the sward came from recently fixed N.

Catch crops, which may include leguminous species, are widely used in organic arable crop rotations to accumulate soil mineral N after harvesting of the main crop. For instance, Askegaard et al. (2005) found a reduction (26–38%) in N leaching through inclusion of grass-clover catch crops in organic crop rotations, indicating a reduction in soil N availability that would be expected to constrain N_2O emissions during autumn–winter. Subsequent tillage operations, however, could increase N availability and N_2O emission due to mineralization of catch crop residues (Millar et al., 2004).

In Europe the area under organic farming increased from 0.1 to 7.8 million hectares within the period 1985–2007 (Willer, 2009), and in Denmark arable crops account for over 60% of the organically farmed area (Schaack, 2009). There is a need to quantify effects of both organic and conventional cropping systems on N_2O emissions, and to identify drivers of these emissions in order to enhance N_2O mitigation efforts. Kaiser and Ruser (2000) summarized several long-term field experiments and concluded that approximately 50% of annual N_2O emissions took place during the winter season. Slower nutrient release patterns from organic compared to inorganic N sources could lead to surges in N_2O emission beyond the crop growing season typically covered, and reliance on short-term measurement campaigns is therefore particularly problematic in studies comparing mineral and organic fertilizers. In order to describe long-term effects, comparative studies should be determined at sites with an extended pre-history of each cropping system, and measurements should cover all seasons.

We report here findings from a 12-month study, where N_2O measurement campaigns were conducted at least twice a month in winter wheat grown within three organic and one conventional crop rotation at two long-term field experiments in Denmark. The objective of the study was to evaluate whether N_2O emissions from cropping systems are affected by management as represented by (1) organic versus conventional farming practices, (2) use of grass-clover ley in the rotation as whole-year green manure, and (3) use of catch crops. In addition, we sought to determine the extent to which soil parameters influence N_2O emissions. It was hypothesized that the restricted availability of N in organically managed systems would lead to lower N_2O emissions compared to the conventional system receiving higher N inputs. We further hypothesized that inclusion of catch crops and grass-clover leys in the rotation would lead to higher N_2O emissions emanating from decomposition of residues accumulating in the soil during spring.

2. Materials and methods

2.1. Site description

The monitoring studies were made in two long-term crop rotation experiments on similarly textured soils at Foulum (56°30′N, 9°34′E) and Flakkebjerg (55°19′N, 11°23′E) in Denmark (Olesen et al., 2000). The Foulum (FO) soil is classified as a sandy loam, Typic Hapludult, with 77.9% sand, 13.3% silt and 8.8% clay in the plough layer (ca. 0–25 cm); 23 g SOC kg^{-1}; 1.8 g total N kg^{-1}; pH 6.5 ($CaCl_2$); 5.4 mg P 100 g^{-1}; 13.1 mg K 100 g^{-1}; 12.3 mequiv. CEC 100 g^{-1}, and a bulk density of 1.35 g cm^{-3}. The soil at Flakkebjerg (FL) is also a sandy loam, Typic Agrudalf, with 72.1% sand, 12.4% silt, 15.5% clay; 10 g SOC kg^{-1}; 1.1 g total N kg^{-1}; pH 7.4 ($CaCl_2$); 3.0 mg P 100 g^{-1}; 9.8 mg K 100 g^{-1}; 10.6 mequiv. CEC 100 g^{-1}, and a bulk density of 1.63 g cm^{-3} (Djurhuus and Olesen, 2000). The Foulum site has a mean annual rainfall of 704 mm, whereas Flakkebjerg receives 626 mm. Mean annual air temperatures are 7.3 °C and 7.8 °C at Foulum and Flakkebjerg, respectively.

2.2. Experimental structure

Identical experimental crop rotations were initiated at the two sites in 1997 (Olesen et al., 2000). The factorial design comprised three factors within two replicate blocks. The factors were (1) proportion of N_2-fixing crops in the rotation, (2) presence (+CC) or absence (−CC) of a catch crop undersown in the cereals or pulse crops in spring, and (3) use of animal manure. Further details on the 1st and 2nd course of the crop rotations are given by Olesen et al. (2000). From 2005, one cropping system, a rotation without catch crops and without manure application, was converted to conventional (C) management, i.e., mineral fertilizers and pesticides were introduced.

This study focused on the winter wheat (*Triticum aestivum* L.) crop present in all crop rotations since 2005 at both Foulum and Flakkebjerg (Table 1). At both sites three organically and one conventionally managed system were selected. The organic rotations included one system based on green manure (grass-clover) with catch crops (O2 + CC), and two systems without green manure, but with or without catch crops (O4 + CC and O4 − CC, respectively). All organic systems received animal manure as pig slurry. The conventional system (C4 − CC) had the same crop composition as O4 rotations, had no catch crops and was fertilized with NH_4NO_3.

In the organic cropping systems undersown with catch crops, either a pure stand of perennial ryegrass or various mixtures of perennial ryegrass, chicory and clover species were used (Olesen et al., 2007, 2009). In some years this undersown catch crop was replaced with catch crop sown after harvest of the main crop to

Table 1
Structure of the four selected four-course crop rotation systems used in this study, including three organic (O) and one conventional (C) system (see text for additional details). Crop rotations with (+CC) and without (−CC) catch crops were included.

Rotation course	O2 + CC	O4 + CC	O4 − CC	C4 − CC
1	s. barley:ley	s. barley^{CC}	s. barley	s. barley
2	Grass-clover	Faba bean^{CC}	Faba bean	Faba bean
3	Potato	Potato	Potato	Potato
4	w. wheat^{CC}	w. wheat^{CC}	w. wheat	w. wheat

CC: catch crop.