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Impact of cover cropping and landscape positions on nitrous oxide emissions in northeastern US agroecosystems

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ABSTRACT

The environmental benefits of organic farming compared to conventional agriculture are well documented, but relatively few studies have assessed their differences in emissions of nitrous oxide (N_2O), a potent greenhouse gas (GHG). The objective of the study was to assess the interactive impact of management and landscape positions on soil characteristics and N_2O emissions. A field-scale experiment was conducted in two adjacent grain farms in upstate New York that have both undergone the same management for 20 years. In the conventional field (CNV), inorganic fertilizer was the only nitrogen (N) source, but in the organic fields (ORG), a legume cover crop, red clover (*Trifolium pratense)*, was frost-seeded into a winter grain (spelt, *Triticum spelta*), and then incorporated in spring as a N source for the subsequent maize plants (*Zea mays*). Measurements of soil properties and N_2O emissions were conducted at shoulder and toeslope positions on both CNV and ORG fields in 2012. Based on Principal Component Analysis, landscape position, management regime, and rotation phases explained 67% of the variation in the soil properties; these three major sources of variation in soil properties (principal components) were correlated significantly with seasonal average N_2O emissions. Comparable N_2O emissions were found from the clover-maize (ORG Cl-M) phase in the ORG field and the bare fallow-maize phase in the CNV field. The spelt-clover phase in the ORG field had the lowest N_2O emissions due to low N availability. In the CNV field, seasonal average N_2O emissions were driven mainly by the elevated gas fluxes after fertilizer application. High soil moisture and inorganic N pools towards the end of the growing season probably resulted in increased denitrification rates. The impact of landscape position on N_2O emissions was mainly found in the CNV field, probably because greater moisture and pH drove greater rates of complete denitrification at toeslope positions. In the ORG Cl-M phase, the seasonal average N_2O emissions were dominated by the emission peaks that immediately followed incorporation of clover. Greater clover biomass at shoulder slope positions resulted in greater N_2O peaks there, but the position effect was not statistically significant. Our study suggests that ecosystem state factors, such as landscape characteristics, interacted with management practices to impact soil properties, crop growth, and microbial communities and, therefore, had interactive effects on N dynamics, including N_2O emissions.

1. Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas (GHG) that is about 310 times more potent than CO_2 on a 100-year time scale, and it is a strong ozone-depletion substance (Forster et al., 2007). Agriculture accounts for ~60% of anthropogenic N_2O emissions, and agricultural soils are the dominant sources (IPCC, 2006). As a result, there is an urgent need to improve management of agricultural nitrogen (N) and to reduce N_2O emissions from agricultural soils.

To design effective N_2O mitigation strategies, it is necessary to understand the broad range of biotic and abiotic factors that control N_2O emissions at various spatial and temporal scales. The classical ecosystem framework that is used to define proximal and distal controls of biogeochemical processes systematically is helpful for understanding the complex network of factors that ultimately control N_2O production processes, such as nitrification and denitrification (Groffman et al., 1988; Robertson, 1989). In agroecosystems, ecosystem state factors such as climate, soils, and topography, combined with management practices, impact ecosystem processes. Landscape characteristics and management practices influence soil properties interactively (Ladoni

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et al., 2016), crop growth (Nazmi et al., 2011) and microbial communities (Wickings et al., 2016), which, in turn, impact the patterns of soil processes such as N mineralization (Ladoni et al., 2015) and N_2O emissions.

Although it is generally accepted that interactions between environmental factors and management practices govern N_2O emissions from agroecosystems, the impact of these interactions has rarely been quantified. Most studies have focused on either management practices alone or on landscape effects under the same management regime and their impact on N_2O emissions (Corre et al., 1996; Gu et al., 2011; Sehy et al., 2003; Vilain et al., 2010). Few studies have focused on the interactive effects. For example, Negassa et al. (2015) examined how cover crops and tillage impacted N_2O emissions at different landscape positions, and they found that variation in N_2O emissions under these distinct management regimes was impacted strongly by landscape position. They were unable to detect any effect of cover crops or tillage alone.

Agricultural landscapes in humid, temperate regions of North America that are outside of the Midwestern "Corn Belt" include a variety of grain production systems. These range from continuous maize monocultures and maize-soybean rotations, which rely primarily on N fertilizer, to highly diversified, legume-based rotations, which rely on biological N fixation as the primary N source. The research on N_2O emissions in grain production systems has focused largely on improved N fertilizer, manure management, and tillage impacts, but only a handful of studies have investigated the impact of alternative strategies such as cover cropping, diversified rotations, and use of green manures (Han et al., 2017). As a result, there are few direct comparisons between the N_2O emissions from Haber-Bosch N-based management regimes and regimes that rely on legume cover crops as N sources.

In upstate New York, the combination of a heterogeneous mixture of cropping systems, where fields with distinct management regimes are located on the same soil types within the rolling landscape of the region, offers an excellent opportunity to study the interacting roles of management and topography on N_2O emissions. In this region, perennial red clover (*Trifolium pratense*) is commonly frost-seeded into a winter cereal crop and allowed to grow as a monoculture following grain harvest. Red clover is then incorporated as an N source for the subsequent crop, which is usually maize. The objective of this study is to compare the effect of conventional, fertilizer-based maize production and diversified, legume-based maize/small grain production on soil development and N_2O emissions, and to document whether these effects differ with landscape position.

2. Methodology

2.1. Experiment design

The experiment was conducted at two commercial grain farms in Penn Yan, New York (42° 40.4′N, 77° 2.12′W). Long-term average annual temperature is 9 °C and average annual precipitation is 819 mm. The organic (ORG) and conventional (CNV) fields were adjacent to each other, and the details of their soil properties and management history can be found in Berthrong et al. (2013). Briefly, the ORG fields had been in a diverse rotation of soybean (*Glycine max*)-spelt-red clover-maize since 1994 with small, periodic additions of animal manures. The CNV field had received N fertilizer and it had been in continuous maize production with occasional dry beans (*Phaseolus vulgaris* L.) for more than 20 years. The N fertilizer application rate in 2012 was 176.2 kg N/ha (Table 1). When we began our sample collection in April 2011, half of the ORG fields were in clover, which was incorporated in May as green manure for maize. The other half of the ORG fields were planted with spelt the previous fall, and clover had been frost-seeded into the spelt during the late winter. Field measurements were conducted from early spring through the maize and spelt harvest in three fields: two ORG fields that represented the two phases of the rotation, clover-maize (hereafter **ORG Cl-M)** and spelt-clover (hereafter **ORG Sp-Cl),** and the adjacent CNV field, bare fallow-maize (hereafter **CNV Br-M**) (Fig. 1, Table 1).

Collection of soil and plant samples and N_2O monitoring were conducted at 18 sites that represented the two management regimes (ORG and CNV) and two landscape positions: ORG = 2 crop rotation phases x 2 landscape positions x 3 replicate sites = 12 sites; CNV = 1 rotation phase x 2 landscape positions x 3 replicate sites = 6 sites. Each site consisted of an area of 20 × 20 m^2 where three chambers were installed to characterize spatial heterogeneity (Fig. 2). All ancillary measurements (described below) were conducted within a 20 cm radius of the three chamber locations. The ORG field had a west-facing slope of 1.4%, where three ORG Cl-M strips and three ORG Sp-Cl strips were laid out alternately. Sample sites for the ORG fields were located at shoulder slope and toeslope positions in each of these strips, which were maintained with identical management practices, but which represented differing points in the rotation (Fig. 2). The CNV field had a large south-facing slope of 1.0% that was divided into two parts, both under the same management regime. Samples were taken from three sites each at the shoulder slope and toeslope positions. For both ORG and CNV fields, all sites at the shoulder slope positions were in the Honeoye soil series (fine-loamy, mixed, active, mesic Glossic Hapludalfs), and all sites at the toeslope positions were in the Lima soil series (fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs).

2.2. Gas measurements

N_2O was measured bi-weekly from early April to October 2012 with closed static chambers. We undertook an event-based measurement to compare management regimes/rotation phases and landscape positions. The chamber design was described in detail in Molodovskaya et al. (2011). Chamber bases were removed for field operations, re-installed at the same locations and stabilized for two weeks before the next sampling. During the maize phase, two chamber bases were placed around maize plants and one chamber was placed between maize rows. When maize plants outgrew the chamber, maize plants were cut down immediately before chamber closure. Chamber bases were then moved to the next adjacent maize plant after each sampling campaign.

During each flux measurement, 14-ml gas samples were taken at 0, 20, 40, and 60 min after the chamber closure. Each gas sample was taken from the headspace of the chamber using a 25-ml syringe. N_2O samples were analyzed by ECD gas chromatography using a GC, Agilent 6890N GC/ECD that was equipped with an HP 7694 headspace autosampler. All data were checked visually to eliminate outliers due to vial leakage or instrument errors. N_2O flux rates were then calculated using the HMR package in R (Pedersen et al., 2010), which compared linear or non-linear regression for gas concentration with time and recommended best fits. Detection limits were 0.006397 ppm m^2 min^{-1} for non-linear fits and 0.00107 ppm m^2 min^{-1} for linear fits that were based on methods described in Parkin et al. (2012). The cumulative N_2O emissions during the measurement period were estimated by linearly interpolating daily N_2O fluxes based on the observed N_2O fluxes and integrating through time.

2.3. Ancillary measurements

Soil samples to the depth of 20 cm were taken at the beginning of the field season (April 2012) and analyzed for total C and N, pH, and particulate organic matter (POM). Total soil C and N were analyzed with a Leco CN-2000 analyzer (Leco Instruments, Lansing, Michigan, US). Measurements of free and occluded POM (fPOM and oPOM, respectively) were conducted according to Marriott and Wander (2006) and Schipanski et al. (2010). pH levels were determined by the 1:1 water method. Bulk density was determined at the end of the field season on Oct 15th, 2012.

Each N_2O sampling campaign also included measurements of soil