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Research Paper

Nitrous oxide emissions with organic crop production depends on fall soil moisture

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ABSTRACT

Agriculture is the major anthropogenic contributor to global nitrous oxide (N_2O) emissions. Many studies have examined soil N_2O emissions from synthetic nitrogen (N) fertilizer additions, however, in organic production where plough-down of forage legumes are often used as a nitrogen source, emissions are as not well understood. In the current study, the Glenlea Long-Term Organic Crop Rotation Study near Winnipeg, Manitoba, was used to compare N_2O emissions of a conventional annual grain and an organic mixed forage-grain system. Static-vented chambers were used to determine N_2O emissions for the 2014 and 2015 crop years; from spring planting to freeze-up and again during thaw following spring. plots monitored were spring wheat and two-cut harvest with late-summer or early-fall plough-down alfalfa for the organic system, and spring wheat and soybean for the conventional system were monitored in each study year. The organically produced alfalfa received composted dairy manure in 2014 and only conventional wheat crops received fertilizer N as urea. Cumulative emissions (g N_2O-N ha^{-1}) with organic wheat were half that of conventional management. Cumulative emissions for the legume crops in the 2014 crop year were very low (< 200 g N ha^{-1}) and not affected by management. No or very low emissions occurred shortly after plough-downs in 2014 and 2015, and during thaw in 2015. However, fall soil moisture was higher in 2015 resulting in nitrate accumulation from alfalfa plough-down and high subsequent N_2O emissions during spring thaw in 2016. Over both study years, management did not affect yield-scaled emissions for wheat unless thaw emissions from ploughed down alfalfa were included. In conclusion, the benefit of organic cropping on N_2O emissions was dependent upon the soil moisture level in fall that preceded the spring thaw period.

1. Introduction

Addition of nitrogen (N) to agricultural land as synthetic nitrogen fertilizers and livestock manures are a major cause of increasing concentrations of the greenhouse and ozone destroying gas, nitrous oxide (N_2O), to the atmosphere (Myhre et al., 2013). Approximately 70% of Canadian anthropogenic N_2O emissions are from agriculture soil and manure management (Environment Canada, 2016). Numerous studies have examined soil N_2O emissions after animal manure application (Tenuta et al., 2010; Asgedom et al., 2014; Gao et al., 2014; Nikièma et al., 2016) and synthetic fertilizer application methods in Prairie region of Canada (Glenn et al., 2012; Tenuta et al., 2016; Gao et al., 2015, 2017) but none reports for organic cropping systems. Determination of soil N_2O emissions from all management systems and N application types is needed to develop sound mitigation strategies as well as for the development in regional and national greenhouse gas inventories.

The value of organic food products sold in the United States of America have more than doubled from 2006 to $40 billion in 2015 (Organic Trade Association, 2016). Organic crop production in Canada is expanding, being 695,000 ha in 2009 and 983,386 ha in 2015 (Agriculture and Agri-Food Canada 2013;Organic Trade Association 2017a). In Canada, the value of organic food products tripled from 2006 to $3.5 billion in 2012 (Organic Trade Association 2017b). Crops in organic production do not receive synthetic fertilizers, rather, N is added as animal manures or composts and plough-down of legumes that fixed N (Entz et al., 2001a). Where many studies have quantified N_2O emissions from N additions of synthetic fertilizers, manure and compost to soil, N_2O from the plough-down of legumes in organic cropping systems is unknown. For conventional systems, plough-down of alfalfa or clover in spring have resulted in large emissions before planting and during the growing season (Wagner-Riddle et al., 1997; Flessa et al., 2002; Peterson et al., 2013). Johnson et al. (2012) reported termination of alfalfa by tillage incorporation in November resulted in increased thaw N_2O emissions the following spring near Morris,

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Minnesota. Organic systems on the Canadian Prairies rely more on late summer termination of alfalfa by ploughing after cutting and may yield different timing and amount of N_2O emissions than early spring and late fall incorporation.

It is uncertain if organic crop production systems emit more or less N_2O than conventional systems. Flessa et al. (2002), Petersen et al. (2006), and Aguilera et al. (2013) reported lower N_2O emissions from organic production systems, but Johnson et al. (2012) and Nadeem et al. (2012) reported greater N_2O emissions. The studies reported in Flessa et al. (2002), Petersen et al. (2006), Nadeem et al. (2012) and Aguilera et al. (2013) were conducted in Europe and Johnson et al. (2012) in Minnesota, USA. Past studies in Europe have been in a very different climate compared to Manitoba, Canada, where long cold winters occur. The study conducted by Johnson et al. (2012) would most resemble the environment of cropped areas of Manitoba, Canada. Both are located in the central continental region of North America and have frozen soils for a portion of the year. However, the study site of Johnson et al. (2012) is south of Manitoba and does have shorter and warmer winters. A comparison of N_2O emissions between organic and conventional production systems in Canada has not been reported.

A constraint to comparing N_2O emissions from organic and conventional cropping systems has been the lack of availability of controlled study sites for monitoring. However, the oldest established organic-conventional cropping system comparison in Canada is present in Manitoba. The Glenlea Long-Term Crop Rotation and Management Study was established in 1992 at the University of Manitoba's Glenlea Research Station and National Centre for Livestock and the Environment (49.39 N and 97.7 W). Conventional and organic management have been compared for crop yield, quality, soil nutrients (Turmel et al., 2009), plant available phosphorus (Welsh et al., 2009), soil carbon (C) and nitrogen stocks (Bell et al., 2012), mycorrhizal colonization (Entz et al., 2004; Welsh et al., 2009; Kirk et al., 2011), bacterial communities (Li et al., 2012), microbial activities, biomass and P contents (Braman et al., 2016), nematode communities (Briar et al., 2012), energy use and efficiency (Entz et al., 2004, 2005; Hoeppner et al., 2005), as well as weeds, diseases, and profitability (Entz et al., 2014). The study provides an opportunity to compare N_2O emissions between a mature organic and conventional cropping system.

In the current study, the Glenlea Long-Term Rotation and Management Study Site in Manitoba was used to compare N_2O emissions from an organic and conventional cropping system. Nitrous oxide emissions were monitored for two years. Legumes not requiring addition of N were monitored; alfalfa (*Medicago sativa* L.) with plough-down in late summer for the organic system and soybean (*Glycine max* L.) for grain in the conventional system. Spring wheat (*Triticum aestivum* L.) was cropped in common following the legumes, with the conventional system receiving synthetic nitrogen fertilizer. Comparison of N_2O emissions between systems was done on an area (g N ha^{-1}) and yield (kg N Mg^{-1} grain) basis for the production of spring wheat.

2. Materials and methods

2.1. Site description

The Glenlea Long Term-Crop Rotation site is located 16 km south of the City of Winnipeg, Manitoba, Canada (49.39 N and 97.7 W; 235 m a s l.). It is located in the Red River Valley, a near-level to very gently sloping (typically < 1 m km^{-1}), glaciolacustrine clay floodplain in Manitoba and neighbouring states of Minnesota and North Dakota. The soil is poorly drained, of the Red River association (Michalyna, 1970), and predominantly a Gleyed Humic Vertisol in the Canadian classification system or fine smectitic frigid Typic Epiaquert in the USA system. The texture of the soil is clay (90 sand, 260 silt, 660 clay g kg^{-1}) with a pH_{H2O} 7.4 and an organic matter content of 77 g kg^{-1} (45 g kg^{-1} organic C). The long-term annual (1981–2010) mean precipitation is 542 mm with 450 mm falling as rain. The long-term annual mean temperature is 2.8° C (Environment Canada, 2015).

2.2. Experimental design

The experimental design of the study site was a randomized complete block with three replicates for conventional and organic production systems. The conventional system has a 4-year cropping sequence of annual grains of, a) flax (*Linum usitatissimum* L.), b) oat (*Avena sativa* L.), c) soybean, and d) hard red spring wheat receiving synthetic fertilizer and herbicide. The organic system has a 4-year cropping sequence of, a) flax for grain, b) subsequent year seeded to alfalfa for hay, c) second year of alfalfa for hay and plough-down, and then d) hard red spring wheat for grain. The study is fully phased such that plots for each crop in the cropping sequence are present every year. The organically produced alfalfa plots received composted dairy manure in 2014 to supply phosphorus. The alfalfa plots were seeded with alfalfa, timothy (*Phleum pretense* L.) and red clover (*Trifolium pretense* L.) at 15 kg ha^{-1}, 2.5 kg ha^{-1}, and 2.5 kg ha^{-1}, respectively, the latter two to help with weed competition. The plot size is 4 × 28 m for the conventional and 4 × 12 m for the organic treatments. Plot size for the organic treatments is smaller than the conventional production treatment plots because they were split to accommodate sub-treatments of with and without compost addition. For the current study, only the organically managed plots that received compost application were monitored because they are more reflective of grower practice to supply phosphorus to soil.

The current study was conducted for the 2014 and 2015 cropping years using the third and fourth year of the cropping sequence of for

Table 1
Agronomic management.

Crop	Management	Variety	Seeding	N Source	N Addition	N Rate	Herbicides	Harvest
			day		day	kg ha^{-1}		day
2014								
Conventional	Soybean	24-10RY	136	–	–	–	glyphosate	269
Organic	Alfalfa	ACCaribou	–	compost	156	62	–	177&227
				plough-down	269	92		
Conventional	Spring wheat	Waskada	136	46 – 0 – 0	135	98	clodinafop-propargyl	260
				11-52-0	135	4		
Organic	Spring wheat	Waskada	136	–	–	–	–	260
2015								
Conventional	Soybean	24-10RY	120	–	–	–	glyphosate	266
Organic	Alfalfa	4020 MF		plough-down	246	85	–	167&215
Conventional	Spring wheat	Waskada	120	46 – 0 – 0	119	98	clodinafop-propargyl	232
				11-52-0	119	4		
Organic	Spring wheat	Waskada	120	–	–	–	–	232