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Response of surface GHG fluxes to long-term manure and inorganic fertilizer application in corn and soybean rotation

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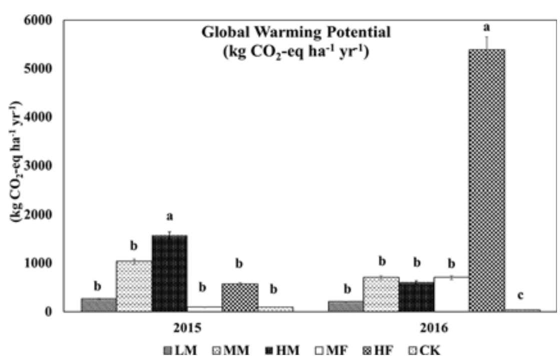
HIGHLIGHTS

- The variations in CO_2 fluxes in 2015 (Soybean) were higher than in 2016 (Corn) due to different crops and fertilizer amounts.
- There were not any significant impacts from manure and inorganic fertilizer application on CH_4 fluxes in both 2015 and 2016.
- Soil surface N_2O fluxes were higher with the addition of higher doze of inorganic fertilizers compared to that of manure.
- The application of higher doze of inorganic fertilizer caused higher emissions compared to those of manure treatment in 2016.

GRAPHICAL ABSTRACT



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ABSTRACT

This study was conducted to investigate the impacts of dairy manure and inorganic fertilizer on soil surface greenhouse gases (GHG) [carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)] fluxes from soils managed under corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation. The experiment was established on a silty loam soil, and the treatments included three manure application rates [phosphorus based recommended rate (low manure, LM), nitrogen based recommended rate (medium manure, MM) and two times recommended nitrogen rate (high manure, HM)], two inorganic fertilizer levels [recommended fertilizer (medium fertilizer, MF) and high rate of fertilizer (HF)], and control (CK) replicated four times. Soil GHG fluxes were monitored once a week during the growing season for 2015 and 2016. Data from this study showed that there were not any significant impacts from manure and inorganic fertilizer applications on the annual CH_4 fluxes in 2015 and 2016. However, annual soil surface CO_2 fluxes were increased by manure treatments compared to inorganic fertilizer treatments in both the years. In contrast, manure treatments decreased N_2O fluxes, but significantly increased net GWP than the fertilizer treatments in 2016. In general, higher manure and fertilizer rates resulted in higher annual GHG emissions compared to lower manure and fertilizer rates in both years. Data from this study showed that HF application in crops can be detrimental for the environment by emitting higher GHG emissions, therefore, improved application strategies for manure and fertilizer management need to be explored to avoid any negative environmental impacts.

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1. Introduction

Agricultural emissions are the major contributing factor to global warming and stratospheric ozone depletion, and thus impacting in regulating the earth's surface temperature and precipitation regimes (Smith et al., 2003). Agricultural soils are responsible for 18% of the greenhouse gases (GHG) emissions (Massé et al., 2011). The concentrations of the GHG, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have become a concern due to their direct impact on the global climate (Marble et al., 2011). The CO_2, CH_4 and N_2O contributing 10–12% to the total global anthropogenic emissions in 2005 (Smith et al., 2008). Therefore, sustainable management practices need to be implemented to mitigate these emissions.

Organic and synthetic fertilizer use is the major sources of GHG emissions from agricultural lands (Kim et al., 2014; Li et al., 2013). Nitrogen fertilizers are important for crop production, but excessive N fertilizer application can increase GHG emissions (Aguilera et al., 2013). Manure, an organic fertilizer, is one of the sources that is responsible for significant amounts of GHG emissions (Bennetzen et al., 2016; Kumar et al., 2014). The US dairy industry produces approximately 2% of the total US GHG emissions that come from the feed, cattle and manure management (Kebreab et al., 2006). Soil CO_2 and CH_4 are produced from manure organic matter degradation, while N_2O is primarily produced after manure application directly by nitrification–denitrification processes or indirectly when N is lost through NH_3 volatilization or nitrate leaching and subsequently converted to N_2O (Sun et al., 2014). Animal manure contains complex organic compounds those are broken down by bacteria resulting in the production of CO_2 under aerobic conditions. According to Sejian et al., 2015, the production of CH_4 (one of the largest carbon source of GHG emission from manure) is affected by the amount of manure produced and the portion of the manure that decomposes anaerobically. Graham et al. (2013) reported that the application of manure produced higher N_2O emissions compared to non-manured soils. Therefore, there is an urgent need for managing the manure in the livestock industry to adopt environmentally sustainable production practices (Massé et al., 2011).

Inorganic fertilizers impact GHG emissions from soil by influencing the processes of microbial decomposition and root respiration by influencing the processes of nitrification and denitrification (Davidson et al., 2000; Toonsiri et al., 2016; Ryan and Law, 2005). The increase in GHG emissions through the application of the inorganic fertilizers has been documented by a number of studies. For example, Kim et al. (2014) reported that inorganic N fertilizer usage significantly resulted in higher CO_2 emissions compared to the control. Application of inorganic N fertilizers has been shown to reduce the CH_4 oxidation and therefore may lead to increased CH_4 emission. Fernández-Luqueño et al. (2010) also reported that the addition of inorganic N fertilizer significantly increased N_2O emissions compared to the non-fertilized soils.

The variation in the environmental conditions should be considered when assessing the effect of different N fertilizers on GHG fluxes (Mbonimpa et al., 2015). Precipitation determines the water filled pore space (WFPS) in soil which impacts GHG fluxes by influencing the oxygen status of the soil (Rafique et al., 2014). The emissions of CH_4 depend on soil moisture and soil temperature, with high soil moisture content favoring CH_4 production (Le Mer and Roger, 2001). Oertel et al. (2016) reported that an increase in soil temperature leads to higher emissions of CO_2 from soils due the increase in the consumption of organic matter. According to Neto et al. (2011), the change in soil temperature had a significant effect on N_2O fluxes.

Improved organic and mineral fertilization management can be an alternate strategy to mitigate GHG emissions and create further resilience to climate change (Bennetzen et al., 2016). However, uncertainty still remains about the overall implications of fertilization rate and type, climate and soil conditions on GHG emissions (Mbonimpa et al., 2015). Little is known about how the rate of fertilizer source (mineral vs. organic) affects GHG fluxes. Evaluating the fertilizer rate of different sources will be of great assistance in minimizing GHG emissions. Therefore, the objective of this study was to assess differences in GHG fluxes when different rates of manure and inorganic fertilizers along with the control (no manure or inorganic fertilizer) were applied under corn-soybean rotation systems.

2. Materials and methods

2.1. Experimental site and experimental design

The experimental site was located at the South Dakota State University Felt Research Farm (44° 22′ 07.15″ N and 96° 47′ 26.45″ W) in Brookings County, South Dakota. Soil type was Vienna soil (Fine-loamy, mixed, frigid Udic Haploborolls). The experimental plots were established in 2008 in a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation system, and treatments were laid out in a randomized complete block design with four replications. The individual plot was 6 m × 18 m in size and managed under a reduced tillage system. Soils of the study site were well drained, and site was established on nearly flat areas with the slope of <1%. The experimental areas were characterized with a continental climate having relatively humid summers, and cold and snowy winters.

2.2. Study treatments

Different N rates of different fertilizer sources were applied in the present study. The study treatments included three manure application rates [(i) low manure N rate (LM), (ii) medium manure rate (MM), and (iii) high manure rate (HM), and two fertilizer application rates [(i) medium inorganic fertilizer rate (MF) and (ii) high inorganic fertilizer rate (HF)], along with control (CK), where neither organic manure nor mineral fertilizer N was applied. The amount of manure and inorganic fertilizer treatments in 2015 and 2016 (Table 1) were calculated using South Dakota Department of Environmental and Natural Resources (DENR) tool and considering crop nutrients needed according to crop yield goal, soil nutrient contents and manure nutrient contents for each treatment. The manure and fertilizer treatments were applied in spring 2015 and 2016 manually and incorporated by disking at 20 cm depth one to three days before planting. Corn was planted in 2015 and soybean in 2016.

2.3. Soil sampling and analysis

Soil samples were collected from 0 to 10 cm depth using a push probe auger in summer of 2015. A total of 4 replicated samples per plot were collected, and these soil samples were composited for each plot and sieved and passed through 2 mm sieve to determine the initial soil properties. At 2015 and 2016 harvesting, soil samples were also collected following the same procedure to determine the effect of the manure and inorganic fertilizer treatments on soil pH, total nitrogen (TN) and soil organic carbon (SOC). In addition to TC and SOC, intact core samples were collected from 0 to 10 cm depth using the core sampler of 5 cm diameter and 5 cm height to measure the soil bulk density.

2.4. Sampling and analysis of greenhouse gas fluxes

The PVC static chambers (25 cm diameter × 15 cm height) were installed in every plot to monitor soil surface GHG fluxes. A chamber was installed between crop rows in each plot throughout the season. Gas samples were taken once a week depending on weather conditions from June through October 2015 and May through October 2016. In addition to soil surface GHG flux monitoring, soil temperature and moisture data for 0–5 cm depth were also collected at every chamber throughout all sampling times. Gas samples were collected at 0, 20 and 40 min intervals using a 10-ml syringe. These samples were taken via a chamber septum and transferred to a 10-ml, argon-filled vials.