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Greenhouse gas mitigation potential of annual and perennial dairy feed crop systems

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A R T I C L E I N F O

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A B S T R A C T

Dairy production constitutes a significant amount of the total global anthropogenic greenhouse gas (GHG) emission. One of the proposed strategies to mitigate GHG emission from dairy production is by enhancing soil carbon sequestration through promoting the growing of perennial over annual dairy feed crop. We determined the net ecosystem carbon budget (NECB) of a hay and corn field grown side-by-side over three years to compare the GHG mitigation potential of perennial over annual feed crops in Elora, Ontario, Canada. The NECB was determined using measurements of net ecosystem exchange (NEE), total plant carbon content, and carbon content in applied dairy manure. The greenhouse gas balance (GHGB) were determined using the NECB plus the total nitrous oxide (N_2O) fluxes measured by a complementary study at the same site. The effect of plowing of the hay field on the NECB and GHGB was also investigated. Our observations indicate that on average over the three study years, NECB of hay ($7 \pm 51\ g\,C\,m^{-2}\,yr^{-1}$) was significantly lower than corn ($154 \pm 79\ g\,C\,m^{-2}\,yr^{-1}$) indicating that corn was a larger carbon source than hay. The three-year average GHGB of 796 and 127 g CO_2-eq $m^{-2}\,yr^{-1}$ for corn and hay, respectively, indicated that corn was a larger emitter of GHG than hay. The NECB was the more dominant factor than N_2O emissions in influencing the outcome of the annual GHGB. We conclude that hay has a larger potential than corn in sequestering carbon and mitigating GHG emission even when emissions from hay plow-down are included.

1. Introduction

The dairy industry is a large source of greenhouse gases (GHG), emitting 1.97 Gt of CO_2-eq in 2007 corresponding to 4% of the global GHG emission (FAO, 2010). The major sources of emission from dairy production at the farm scale are enteric fermentation (a source of methane, CH_4), manure storage (a source of CH_4 and nitrous oxide, N_2O), manure and fertilizer use in growing feed crop (N_2O) and use of energy for farm machinery and drying of grain feed (CO_2) (McGeough et al., 2012; Vergé et al., 2007; Rotz et al., 2010).

In an effort to mitigate GHG emission from the dairy sector, one of the mitigation strategies proposed is to reduce growing annual crops for animal feed and alternatively increase the acreage of farm land in perennial crops (Conant et al., 2001; Paustian et al., 2016; Soussana et al., 2010). Cropping systems with perennials have been shown to have higher potential over annuals in sequestering carbon due to their large belowground biomass production and turnover, and less frequent tillage compared to annuals (Soussana et al., 2004). The reduced tillage frequency not only avoids breaking up soil aggregates and exposing physically protected soil organic carbon (SOC), but also reduces CO_2 emission from the consumption of fossil fuel for tillage operation (Lal, 2004).

Conant et al. (2001) observed that conversion of an existing annual cropland to perennial grassland yielded the highest rate of SOC increase among the other management techniques intended to increase SOC by increasing forage production. Hawkins et al. (2015) used an optimization model that considered a range of rations used in intensive milk production and suggested that replacing annual corn silage with perennial alfalfa hay as the primary roughage component can lead to significant decline in GHG emissions from milk production. However, the carbon sequestration potential of corn and perennial hay needs to be quantified in field studies.

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The net ecosystem carbon budget (NECB) was used to determine the short-term change of sequestered carbon in an ecosystem, as significant changes in SOC cannot be detected in a timescale of between 5 and 10 years (Smith, 2004). The NECB is the balance between gains in carbon to the system through plant carbon accumulation and manure application, and what is lost through net ecosystem exchange (NEE) and plant removal from harvest. As soil type and climate conditions can greatly affect NEE (Law et al., 2002), it is important for comparisons between different crop types to be conducted in close proximity to each other.

Numerous studies on quantifying NECB have been previously conducted on hay and corn but with variable conclusions within each respective crop system. Studies by Hirata et al. (2013) and Taylor et al. (2013), for example, showed hay as a carbon sink, while that of Alberti et al. (2010) and Skinner (2007) observed hay was a carbon source. Corn systems studied by Verma et al. (2005) and Loubet et al. (2011) were carbon sinks while studies by Alberti et al. (2010), Ceschia et al. (2010), Glenn et al. (2010) and Jans et al. (2010) showed corn was a carbon source. The contradicting findings of the previous studies can be largely related to management practices, specifically the amount of biomass harvested and amount of carbon returned as manure as almost all of the studies showed the annual cumulated NEE to be negative (CO_2 sink).

To our knowledge, few studies have previously compared the NECB of annual crop versus perennial hay from side-by-side grown crop fields. One of those studies was by Alberti et al. (2010) who studied the effects of switching from planting corn to alfalfa in Northern Italy for two years. They observed that an annual to perennial crop conversion resulted in the perennial alfalfa in being a larger carbon source compared to corn, which contradicted the general notion that perennial hay has greater potential to sequester carbon compared to annual crop. In contrast, several perennial grass species grown for biofuel production acted as carbon sinks whereas a corn-soybean rotation was a carbon source (Zeri et al., 2011). Taylor et al. (2013) studied the effects of switching crop from perennial hay to annual oat and found that the perennial hay that was maintained and not converted to annuals was a carbon sink at the end of their study while the converted plot became a carbon source.

Renovating hay fields is a common practice carried out to increase hay production. It involves removing weeds and pests; improving drainage, aeration and contour of the field; and replacing low-producing hay (Bruns, 2012; Stevens et al., 2007). One of the more intense renovating methods is the complete turnover of the soil by plowing followed by reseeding. This is often preferred over less intense methods such as direct seed drilling for the benefits of controlling weeds and improving aeration (Rutledge et al., 2014). Tillage can possibly increase CO_2 emission due to soil aggregates being broken up, exposing physically protected SOC. Effects of tillage on N_2O, however, is inconsistent with some studies finding increased N_2O emission (Wagner-Riddle et al., 2007), reduced N_2O emission (Beheydt et al., 2008) and also inconsistent result between years (Gregorich et al., 2008) or timing within the year (Rochette and Angers, 1999). Accordingly, the effect of plowing hay on its NEE, NECB and GHG balance (GHGB; the sum of NECB and N_2O emission expressed in CO_2-equivalent) was also determined in the present study by plowing down the hay field in the final year of the study.

The objectives of this study were (1) to quantify and compare the NEE and NECB of a corn and hay field; (2) to calculate the GHGB of a corn and hay field considering NECB, and N_2O emissions from a previously published study conducted in the same fields; and (3) to investigate the effects of plowing a hay field on its annual NEE, NECB and GHGB.

Table 1
Soil physical and chemical properties at different depths.

Depth (cm)	Bulk density (g cm^{-3})	pH	C (%)	N (%)	P	K (ppm)	Mg	Texture
0–15	1.26	7.5	2.57	0.25	26.9	180.0	521.9	Silt loam
15–30	1.49	7.6	1.50	0.14	9.8	101.3	462.5	Silt loam
30–45	1.72	7.8	0.86	0.12	3.3	75.8	343.1	Loam

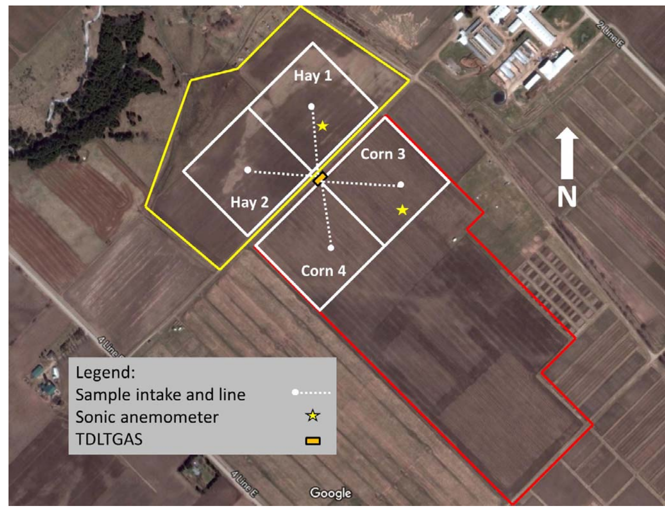

Fig. 1. Aerial view of the study site and schematic of the plot layout and position of the intakes, sonic anemometers and the tunable diode laser gas analyzer system (TDLTGAS). Area bordered by yellow and red lines are the hay and corn fields respectively. The area surrounded by white frames shows the study plots (Map data: Google, DigitalGlobe). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

2.1. Site description

This study was conducted at the Elora Research Station, Ontario, Canada (43°38′27.8″ N 80°24′20.4″ W). The soil at the site is a Guelph silt loam (fine loamy, mixed, *mesic Glossoboric Hapludalf*). Select soil physical and chemical properties are listed in Table 1.

The study was set up on four 4-ha areas (Fig. 1). Two plots were cropped continuously to corn (*Zea mays*) from 2012 to 2014 planted at a seeding rate of 74,000 ha^{-1}. Corn was planted on May 10, May 9 and May 26 and harvested on October 2, October 22 and November 4 in years 2012, 2013 and 2014, respectively; with cultivars Pioneer® N19D-3110, DKC38-03 RIB Brand Blend® and Pioneer®N21J-3220 E-Z Refuge planted in years 2012, 2013 and 2014, respectively. Annual crops had been grown in the two plots for more than 10 years (soybean, winter-wheat, or corn). The two plots planted to corn were part of a 30-ha (to southeast) area planted with the same crop (Fig. 1).

A hay crop was established in 2008 in the other two plots and consisted of a grass (*Phleum pratense* L.) and legume (*Medicago sativa* L.) mixture planted at rates of 6 and 10 kg seed ha^{-1}, respectively. Hay was cut once in 2012 on May 30 and was cut twice in 2013, on June 14 and August 28. On October 16, 2013, the hay was plowed down (20-cm depth) and reseeded with *Medicago sativa* L. cv. Pioneer® 53Q32 on May 26, 2014 at a seeding rate of 18 kg ha^{-1}. Hay in 2014 was cut twice, on July 27 and August 18. The area surrounding the hay plots to the northeast and southwest was also grown in hay to ensure the area was