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Soil–atmosphere exchange of carbon dioxide, methane and nitrous oxide in shelterbelts compared with adjacent cropped fields

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ABSTRACT

Farm shelterbelts are used as a management tool to reduce erosion, conserve moisture, protect crops and buildings, and sequester carbon. Although carbon storage in shelterbelts has been well researched, there have been no measurements of soil trace gas exchange in shelterbelts relative to cropped fields. Our objective was to quantify, for the first time, soil CO_2, CH_4 and N_2O fluxes from shelterbelts and compare them to emissions from adjacent cropped fields to assess their potential for greenhouse gas (GHG) mitigation. During 2013 and 2014, non-steady state vented chambers were used to monitor soil GHG fluxes from nine shelterbelts and their associated cropped fields at three locations within the Boreal plains and Prairies Eco-zones of Saskatchewan Canada. Mean cumulative CO_2 emissions from shelterbelt soils were significantly ($P < 0.0001$) greater than those from cropped fields (i.e., 4.1 and 2.1 Mg CO_2-C ha^{-1} yr^{-1}, respectively). However, soil organic carbon (SOC) storage (0–30 cm) was 27% greater – representing an increase of 28 Mg ha^{-1} – in the shelterbelts than in the cropped fields. Soil CH_4 oxidation was greater ($P < 0.0001$) in shelterbelts than in adjacent cropped fields (i.e., −0.66 and −0.19 kg CH_4-C ha^{-1} yr^{-1}, respectively) and cropped soils emitted significantly ($P < 0.0001$) greater quantities of N_2O than the shelterbelts (i.e., 2.5 and 0.65 kg N_2O-N ha^{-1} yr^{-1}, respectively). Total seasonal exchange of non-CO_2 GHGs was reduced by 0.55 Mg CO_2e ha^{-1} yr^{-1} in shelterbelts as compared with cropped fields, 98% of which was soil-derived N_2O. Patterns of soil temperature, moisture and organic matter distribution beneath shelterbelts suggest a modification in soil micro-environment due to shelterbelt establishment and root activity that, in turn, may be responsible for the observed increase in soil CO_2 emissions and CH_4 oxidation. Our data demonstrate that shelterbelts have substantial potential to mitigate GHGs by enhancing C storage and reducing N_2O emissions, while maintaining a strong CH_4 sink.

1. Introduction

Agricultural lands are being pressed to provide more environmental and economic services as a consequence of the increased global demand for food and other agricultural products. However, as a result of increases in fertilizer use, livestock herd size and tillage that followed the industrial revolution atmospheric concentrations of CO_2, CH_4 and N_2O have increased dramatically (Ruddiman, 2003). Average global temperatures have increased by approximately 0.75 °C over the past century and it is likely that further increases in atmospheric GHG concentrations will result in additional increases in global temperatures (IPCC, 2013).

Promoting agroforestry systems has been recognized as a viable land-use alternative for mitigating the impact of agriculture on climate change; and shelterbelts have been targeted as a strategy for biological C sequestration (Kort and Turnock, 1999). Agricultural lands therefore, present an opportunity for removing large amounts of atmospheric GHGs if trees are incorporated into farm systems (Nair, 2011). Shelterbelts (also known as windbreaks) are linear arrays of trees and shrubs planted to alter environmental conditions in agricultural systems while providing a variety of economic, social and ecological benefits valued by land owners (Mize et al., 2008)—including C sequestration (Kort and Turnock 1999).

Despite occupying only a small land area in agricultural landscapes, shelterbelts can sequester large amounts of C on a per unit area basis. For example, above- and belowground components in shelterbelts can potentially sequester as much as 6.4 Mg C ha^{-1} yr^{-1} (Udawatta and Jose, 2011), though this rate may vary with the age and species of the shelterbelt and with climate factors. Brandle et al. (1992) estimated carbon (C) stored in aboveground biomass of 20-year old, single row conifers, hardwoods and shrubs at 9.14, 5.41 and 0.68 t km^{-1}, respectively. Shelterbelt establishment also has been demonstrated to increase

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soil C stocks compared to conventional cropping systems. Sauer et al. (2007) reported that soil C stocks were significantly greater (by 371 g m^{-2}) in a 35-year-old red cedar-Scots pine shelterbelt compared to cultivated fields. An additional 1300 g C m^{-2} was contained in the shelterbelt tree litter layer. Therefore, in addition to reducing wind erosion and providing other environmental services, shelterbelt systems offer a viable option for enhancing C quantities on marginal parts of agricultural landscapes (Nair, 2011).

While C sequestration in woody biomass (Kort and Turnock, 1999) and soils beneath shelterbelts (Sauer et al., 2007) is synonymous to CO_2 mitigation, little else is known about the influence of shelterbelts on agricultural GHGs. Yet this information is necessary for an accurate assessment of the potential mitigating effects of shelterbelts on agricultural GHG emissions, and in developing future GHG estimates and inventories from shelterbelt systems (Davis et al., 2012).

Biotic and abiotic factors unique to shelterbelts may affect GHG fluxes from soils. The microclimate in the woodland and on the lee side of shelterbelts is modified; e.g., air temperature and evapotranspiration are reduced, while humidity is increased (Zhang et al., 2012). Moreover, well-developed canopies protect soil microfauna from temperature and moisture stress (Martius et al., 2004), while the addition of litter and interception of organic matter-rich windblown sediments contribute to increased SOC content in shelterbelts (Sauer et al., 2007). As well, trees are deep rooting and can inhibit the denitrification process in the soil profile by taking up residual nitrogen (N) and excess soil water that would otherwise be available for N_2O emission or nitrate (NO_3^-) leaching (Allen et al., 2004). These factors can affect net GHG fluxes in shelterbelt systems through their influence on soil microbial communities, root activity, and SOC inputs and decomposition (Zhang et al., 2012).

The Agriculture and Agri-Food Canada Prairie Shelterbelt Program has distributed over 600 million shelterbelt trees across the Prairie Provinces since 1903 to reduce wind erosion and provide other environmental benefits (Wiseman et al., 2009). Similarly, shelterbelts have been planted extensively in the Great Plains of the US. However, there have been no studies quantifying GHG exchange in shelterbelts relative to cultivated fields to determine the full capacity of shelterbelts in mitigating agricultural GHG emissions. The objective of this study, therefore, was to quantify for the first time, soil-atmosphere exchange of CO_2, CH_4 and N_2O in shelterbelts compared to adjacent crop fields.

2. Materials and methods

2.1. Study area

The study area consisted of nine paired shelterbelts and adjacent cropped fields located at three sites in the Boreal Plain (Boreal Transition Ecoregion; Prince Albert, SK) and Prairie (Mixed Moist Grassland Ecoregion; Saskatoon and Outlook, SK) Ecozones of Saskatchewan, Canada (Table 1). To avoid root interactions and shading effects, the cropped field adjacent to each shelterbelt was sampled along a transect running perpendicular to the shelterbelt, with the first plot located at least 50 m from the shelterbelt. Basic site and management characteristics of the shelterbelt and cropped sites are presented in Tables 1–3 .

2.1.1. Outlook

The Outlook site is located at the Canada Saskatchewan Irrigation Diversification Centre (CSIDC). Average temperature and cumulative precipitation during the sampling period (April–October) were 12.5 °C and 278 mm, respectively (based on 1981–2010 climate norms; Environment Canada, 2015). The soils are classified as Orthic Dark Brown Chernozems, a mix of Asquith and Bradwell Association, with moderately sandy loam textures. The site features well drained soils formed mainly in aeolian sands and loamy lacustrine materials on a slightly undulating topography.

The shelterbelt plots consisted of a one row shelterbelt consisting of Scots pine (*Pinus sylvestris* L.) (O-SB1); a one row mixed species shelterbelt consisting of green ash (*Fraxinus pennsylvanica* Marsh.) and caragana (*Caragana arborescens*) (O-SB2); and a single row of caragana (O-SB3). In 2013, the field sites were cropped to wheat (O-CF1) and soybean (*Glycine max* L. Merr.; O-CF2 and O-CF3). In 2014, the O-CF1 site was cropped to soybean while the O-CF2 and O-CF3 sites were cropped to wheat. The cropped field sites received a total of 87.5 and 112.5 mm of irrigation water during the 2013 and 2014 growing seasons, respectively.

2.1.2. Saskatoon

The Saskatoon site is located at the University of Saskatchewan Horticulture Field Research Station. Mean temperature and cumulative precipitation during the sampling period (April–October) were 12.4 °C and 277 mm, respectively (based on 1981–2010 climate norms; Environment Canada, 2015). The soils are classified as Orthic to slightly Solonetzic Dark Brown

Table 1
Site information for the three study sites located in Saskatchewan, Canada.

Parameter	Sites		
	Outlook	Saskatoon	Prince Albert
Ecozone	Prairie	Prairie	Boreal Plain
Ecoregion	Moist Mixed Grassland	Moist mixed grassland	Boreal transition
Soil classification	Dark Brown Chernozem	Dark Brown Chernozem	Black Chernozem
Soil Texture	Sandy loam	Clay	Sandy loam
Latitude (°N)	51.29°N	52.12°N	53.22°N
Longitude (°W)	107.03°W	106.62°W	105.68°W
Elevation (m)	541.0	504.1	428.2
Mean annual air temperature (°C)—2013[a]	15.5	15.3	14.5
Cumulative annual PPT (mm)—2013[a]	181.0	200.5	332.6
Total irrigation (mm)—2013	87.5	NA	NA
Mean annual air temperature (°C)—2014[a]	12.9	12.5	11.4
Cumulative annual PPT (mm)—2014[a]	328.2	310.2	466.6
Total irrigation (mm)—2014	112.5	NA	NA

Note: average air temperature and total precipitation were calculated for the sampling period in each year (April–October). NA = not applicable. PPT = precipitation.

[a] Data from Environment Canada (2014).