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Original research

Greenhouse gas emissions along a shelterbelt-cropped field transect

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A B S T R A C T

The influence of shelterbelts on soil properties and crop yield at various distances from the shelterbelt have been studied; however, there are no available data detailing the spatial effects from shelterbelts into adjacent cropped fields on soil-derived greenhouse gas (GHG) emissions. The objective of this study was to quantify, for the first time, changes in soil CO_2, CH_4 and N_2O fluxes along replicate (n = 5) transects extending from the center of the shelterbelt to the center of the adjacent agricultural field. The shelterbelt was a 31-year-old, two-row hybrid poplar-caragana shelterbelt located in the parkland region of Saskatchewan Canada. Soil-derived GHG fluxes were measured using non-steady-state vented chambers placed along parallel transects situated within the shelterbelt strip (0H), at the shelterbelt edge (0.2H), at the edge of the adjacent cropped field (0.5H), and in the cropped field at distances of 40 m (1.5H) and 125 m (5H) from the shelterbelt. Summed over the entire study period, cumulative CO_2 emissions were greatest at 0H (8032 ± 502 kg CO_2-C ha^{-1}) and lowest at 5H (3348 ± 329 kg CO_2-C ha^{-1}); however, the decrease in CO_2 emissions at increasing distances away from the shelterbelt was irregular, with soil temperature and organic carbon distribution being the dominant controls. Soil CH_4 oxidation was greatest at 0H (−1447 ± 216 g CH_4-C ha^{-1}), but decreased as distance from the shelterbelt increased. Conversely, soil N_2O emissions were lowest at 0H (345 ± 15 g N_2O-N ha^{-1}) but increased with increasing distance from the shelterbelt. Patterns of soil CH_4 uptake and N_2O emissions were strongly correlated with root biomass, and soil temperature and moisture in the upper 30 cm of the soil profile. Tree root distribution may be a key factor in determining the spatial range of shelterbelt effect on GHG emissions in adjacent fields

1. Introduction

For more than a century over 600 million shelterbelt trees have been distributed to Prairies land owners under the provisions of the Prairie Farm Rehabilitation Act, to protect Canadian farms from wind erosion (Wiseman et al., 2009). In Saskatchewan alone it is estimated that there are over 60,000 km of planted shelterbelts throughout the province, and considerably more in the Canadian Prairies (Amichev et al., 2014). The planting of shelterbelts is also recognized as a strategy for mitigating atmospheric CO_2 through C sequestration in tree biomass (Kort and Turnock, 1999) and in SOC pools (Sauer et al., 2007). However, there have been no studies detailing the effects of shelterbelts on the emissions of soil-derived CO_2, CH_4 and N_2O in adjacent cultivated fields; i.e., at varying distances from the shelterbelt.

Shelterbelts have a measurable influence on soil properties in adjacent cropped fields (Kowalchuk and Jong, 1995) and, as such, could affect the exchange of soil-derived GHGs. Changes in soil properties following shelterbelt establishment are a result of modification of local soil microclimate, soil organic matter (SOM) and tree root distribution in adjacent soils (Kort, 1988; Sauer et al., 2007). In general, the leeside of a shelterbelt is characterized by increased springtime soil moisture and relative humidity, along with reduced evaporation and night-time air temperatures (Rosenberg, 1974). At the same time, tree roots continuously extract soil moisture from an area 1.5- to 2-times the height of the shelterbelt (i.e., 1.5H–2H) (Kowalchuk and Jong, 1995). Although the extraction of soil moisture by tree roots is partly offset by increased spring moisture through snow accumulation, it may result in severe competition for moisture between tree roots and crops, particularly in dry years (Kort, 1988).

Like other agroforestry systems, shelterbelts have the potential to maintain or increase SOC, mainly through root turnover and the continuous addition of litter to the soil (Amadi et al., 2016). Studies

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have shown increased soil organic carbon (SOC) content in soils underneath trees compared to adjacent cropped fields (Dhillon and Van Rees, 2017). Bronick and Lal (2005) reported that SOC in wooded soils was about twice that in the adjacent cropped field. In an assessment of SOC dynamics and sources in two 35-year old coniferous shelterbelts, Hernandez-Ramirez et al. (2011) reported that SOC in the shelterbelts was more than 57% greater than that in the adjacent cropped fields. The increase in SOM content within the shelterbelts was explained by a combination of long-term additions of tree litter debris and the entrapment of organic matter-rich wind-blown sediments (Sauer et al., 2007; Amadi et al., 2016).

In addition to their influence on soil physical and chemical properties, shelterbelts and other tree based systems have a positive impact on microbial abundance and diversity (Wojewoda and Russel, 2003). Despite making up only 1–3% of the total soil SOM (Martens, 1995), soil microbial communities play important roles in catalyzing nutrient transformations and biogeochemical cycling in the biosphere (Wojewoda and Russel, 2003; Lacombe et al., 2009), as well as soil exchange of GHG gases (Ellert and Janzen, 2008). Shelterbelts with a well-developed canopy have been shown to protect soil micro fauna from high temperature variations and moisture stress (Martius et al., 2004). As well, Karg et al. (2003) reported greater faunal and microbial biomass in soils beneath a shelterbelt, which decreased with increasing distance from the shelterbelt. Thus, shelterbelt-induced improvements in microbial and faunal biomass could have a measurable effect on the dynamics of soil GHG exchange in the transition zone between the shelterbelt and the adjacent agricultural (cropped) field. Moreover, Wojewoda and Russel (2003) reported a strong positive correlation among soil microbial biomass, soil respiration and SOM distribution at various distances away from the shelterbelt, suggesting that soil microbial activity influences SOM distribution, soil respiration and perhaps soil GHG emissions within this transition zone.

Through their effect on soil physical, chemical and biological properties, shelterbelts are known to influence crop yield in the transition zone extending outward from the shelterbelt strip into the adjacent agricultural field. Kort (1988) reported no crop yield at a distance of 0H–0.5H; a 50% reduction in yield due to root competition at distances from 0.5H to 1H; and a shelterbelt-induced increase in crop yield at distances from 1.5H to 15H, with the largest increase occurring at distances between 1.5H–3H. Overall, the average yield in the area under the influence of the shelterbelt (i.e., at a distance of 0H–15H) was about 3.5% greater than that at the field center, which was not influenced by the trees. In a similar study, Kowalchuk and Jong (1995) reported peak soil N and P concentrations at 2H, which was described as a zone with less root competition and enhanced shelterbelt-induced reductions in wind speed and evaporation.

Information on the effects of shelterbelts on GHG emissions in the shelterbelt/ag-field transition zone (SATZ) is needed to develop accurate estimates of the C sequestration and GHG mitigation potential of shelterbelts for regional C budgets and GHG inventories. Moreover, data on how shelterbelts influence the dynamics of soil C distribution and GHG fluxes in the surrounding soils will lead to more accurate estimations of the environmental and economic benefits of shelterbelt establishment, which in turn will support policy and management decisions on shelterbelt systems. Given the thousands of kilometers of planted shelterbelts throughout the Canadian prairies (Wiseman et al., 2009; Amichev et al., 2014), the impact of shelterbelts on C-sequestration and mitigation of soil GHG in adjacent croplands may be of significant environmental importance. Indeed, our hypothesis is that the dynamics of GHG exchange within the SATZ will vary with shelterbelt-induced changes in soil properties. Thus, the objective of this study was to quantify the influence of a typical prairie shelterbelt on soil-atmosphere exchange of CO_2, CH_4 and N_2O within the SATZ.

2. Materials and methods

2.1. Study area

Studies were carried out at the Conservation Learning Centre, located approximately 18 km south of Prince Albert, within the parkland region of Saskatchewan, Canada (53°01′N, 105°46′W). Climate data for the 2013 (May through October) and 2014 (April through October) sampling seasons were obtained from the Environment Canada meteorological station located at Prince Albert, SK (Environment Canada, 2015). The soils in the study area are classified as Orthic Black Chernozems (Udic Boroll) on a gently sloping topography and with a fine sandy loam texture (Soil Classification Working Group, 1998).

The research site consisted of a 31-year old shelterbelt strip (planted in 1982) running east-to-west along the southern edge of an adjacent agricultural field and the transition zone extending into the cropped field. The strip was a two-row shelterbelt comprised of a row of hybrid poplar (*Populus* spp.) and a row of caragana (*Caragana arborescens*). The hybrid poplar had an average diameter at breast height (DBH) of 52.7 cm, with an average height of 25 m and a spacing of 2 m between trees; the caragana had an average height of 6 m and a spacing of 1 m between trees. The entire shelterbelt strip was approximately 200 m long and 10 m wide. For purposes of this study, the SATZ was defined as the area extending outward from the center of the shelterbelt and to the center of the cropped field, and includes (a) the shelterbelt zone (0H - 0.2H; i.e., the region directly under the tree canopy), (b) transition zone (ecotone), (0.2H – 1.5H; i.e., the area between the shelterbelt zone and the cropped field that is indirectly influenced by shelterbelts, e.g., through shading effect, root activity, litter depositions and micro climatic influences, and (c) cropped zone (1.5 – 5H; i.e. the area of the field that is not influenced by the shelterbelts or are under a limited influence (Wojewuda and Russel, 2003). There was no understory vegetation directly under the shelterbelt; however, various grasses (Primarily *Fescue* spp.) dominated the outer edge of the shelterbelt.

The site, including the cropped field, is characterized by remnant native upland areas and wetlands with an undulating topography. The cropped field extended to within 12 m of the base of the trees and was seeded to barley (*Hordeum vulgare*) on May 21, 2013. In addition, urea fertilizer (equivalent to 50 kg N ha^{-1}) was applied at seeding. In 2014, snowmelt and early season rains resulted in the field not being tilled until June. This, together with excessive amounts of residue, resulted in the field being left fallow (and without fertilizer) during 2014 season.

2.2. Gas sampling and analysis

During the fall of 2012, five transects perpendicular to the shelterbelt were established at various distances along the shelterbelt. The height (H) of a shelterbelt is often used as a standard guide for establishing transects to assess the effect of the shelterbelt on an adjacent field (Kort, 1988; Kowalchuk and Jong, 1995). In the present study, the transects were set perpendicular to the shelterbelt and parallel to one another at a spacing of 20-m between transects. Each transect consisted of five sampling points located at (i) the center of the shelterbelt (0H; located between the rows of hybrid poplar and caragana); (ii) at the outer edge of the shelterbelt, 5-m from the center location (0.2H); (iii) at the inner edge of the cropped field, 12.5-m from the center of the shelterbelt (0.5H); and (iv) within the cropped field at distances of 40-m (1.5H)