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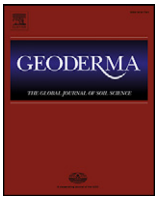

# Will changes in climate and land use affect soil organic matter composition? Evidence from an ecotonal climosequence

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## ABSTRACT

As the largest actively cycling pool of terrestrial C, the response of soil organic matter (SOM) to climate change may greatly affect global C cycling and climate change feedbacks. Despite the influence of SOM chemistry—here defined as soil organic C (SOC) and soil organic N (SON) functional groups and compounds—on decomposition, uncertainty exists regarding the response of SOM chemistry to climate change and associated land use shifts. Here, we adopt a climosequence approach, using latitude along a uniform glacial till deposit at the grassland–forest ecotone in central Canada as a surrogate for the effects of climate change on SOM chemistry. Additionally, we evaluate differences in SOM chemistry from paired native grassland, native trembling aspen (*Populus tremuloides*) forest, and arable soil profiles to investigate the effects of likely climate-induced land use alterations. The combination of C and N *K*-edge X-ray absorption near edge structure (XANES) with pyrolysis-field ionization mass spectrometry (Py-FIMS) techniques was used to examine SOM chemistry at atomic and molecular scales, respectively. These techniques revealed only modest differences in surface SOM chemistry related to land use and latitude. Greater variation was apparent in the vertical stratification of SOM constituents from soil depth profiles. These findings indicate that pedon-scale processes have greater control over SOM chemistry than do processes operating on landscape (e.g. land use) and regional (e.g. climate) scales. Additionally they imply that SOM chemistry is largely unresponsive to climatic change on the magnitude of the mean annual temperature (MAT) gradient under study (~0.7 °C), despite its location at the grassland–forest boundary highlighting its sensitivity, and is similarly unresponsive to associated land use shifts.

## 1. Introduction

Soils, representing the largest actively cycling pool of terrestrial C (Janzen, 2004), have the capacity to affect climate change by influencing atmospheric $CO_2$ concentrations. However, the direction and magnitude of the response of SOC to climate change remain uncertain due to the complexity of dynamics controlling litter input and SOM decomposition (Davidson and Janssens, 2006). The importance of SOC and SON chemistry (hereafter referred to as 'SOM chemistry') in defining SOM persistence, though recently questioned (Schmidt et al., 2011), may remain an important control on SOM turnover. However interactions of SOM chemistry with climate change and associated land use shifts remain to be fully explored.

Paleorecords of rapid forest-to-grassland conversions at the prairie–forest ecotone in central Canada suggest that this region is particularly sensitive to environmental change (Williams et al., 2009). The median prediction from the six IPCC climate change scenarios indicates that by 2020 this region is predicted to experience a ~2 °C increase in MAT relative to the 1961–1990 average; concomitant increases in precipitation will be insufficient to offset increasing evapotranspiration (Sauchyn and Kulshreshtha, 2008). These future drying trends may trigger abrupt vegetation shifts (Williams et al., 2009). Additionally, ongoing agricultural conversion of native forests in the region (Fitzsimmons, 2002) may increase as food demand grows and warming trends continue. Such vegetation shifts and agricultural conversion at the prairie–forest ecotone may alter SOM chemistry and its vertical distribution in soil profiles, with potential implications for SOM persistence.

Accordingly, the analysis of SOM chemistry along a pedogenically defensible climosequence using multiple analytical techniques represents a unique opportunity to isolate effects of climate and land use. Here, we combine synchrotron-based C- and N-XANES with Py-FIMS to examine SOM chemistry. These methods provide complementary information on SOM chemistry, as XANES probes bulk functional group chemistry (Leinweber et al., 2013), while Py-FIMS is a thermally-resolved, high resolution mass spectrometric method identifying SOM composition on the molecular-level (Leinweber et al., 2009a; Schnitzer and Schulten, 1992). Notably, these techniques are particularly well suited to the examination of SON. In contrast to other pyrolytic analytical methods, the step-wise heating of samples using Py-FIMS limits the formation of heterocyclic-N compounds as artifacts. Similarly,

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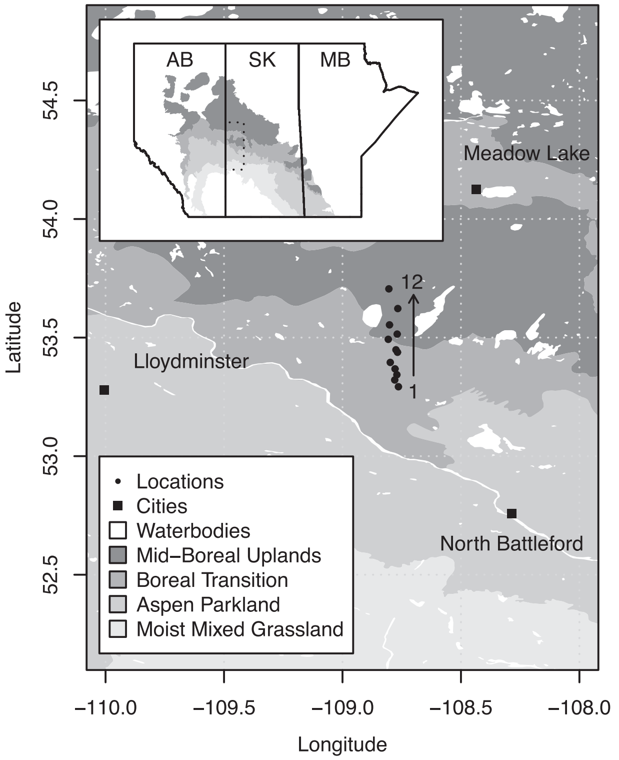

**Fig. 1.** Map depicting study area. Points indicate locations 1 through 12. The inset map depicts the location of the study area in the Canadian Prairies.

while techniques such as $^{15}$N nuclear magnetic resonance (NMR) are limited by low natural $^{15}$N abundance, XANES probes the electronic structure of all compounds containing the element of interest in a sample (Leinweber et al., 2013). Ours is the first study to apply these advanced techniques to soils from a climosequence study design that controls for confounding pedogenic factors.

Here, we explore the effects of climate change and associated land use shifts on SOM composition by characterizing native grassland, native trembling aspen, and arable soils along a climosequence in Saskatchewan, Canada. We utilize changes in SOM chemistry that occur with latitude as a surrogate for climate change effects and examine the impacts of associated land use shifts on surface SOM. Furthermore, we examine soil profiles to 20 cm depth to elucidate land use effects on SOM chemistry and its vertical distribution.

## 2. Materials and methods

### 2.1. Sites and sampling design

Twelve locations (denoted 1–12, south to north) on a uniform glacial till deposit ('Ice-Stream 1' described by Ó Cofaigh et al., 2009) were selected to comprise a 46-km climosequence across the prairie–forest ecotone in west-central Saskatchewan (Fig. 1). Along the climosequence, increasing latitude and a concomitant gradual ~85 m increase in elevation cause MAT to decrease from 0.9 °C to 0.2 °C and mean annual precipitation (MAP) to increase from 418 to 443 mm (Hijmans et al., 2005). While this climatic gradient is of a smaller magnitude than expected changes in MAT, its location at the grassland–forest boundary suggests that it represents a climatic threshold, responsible for a distinctive vegetation shift, and therefore should be a sensitive indicator for future change. Here, the prairie–forest boundary was relatively static (from 10 to 6 ka and 2 to 0 ka) or in a period of forest encroachment (from 6 to 2 ka) during the past 10,000 years (Williams et al., 2009). As such, native forests ($n = 12$), arable fields ($n = 12$), and where available, native grasslands ($n = 4$) were sampled at each location. Forest sites were characterized by an overstorey of mature trembling aspen (*Populus tremuloides* Michx.), with characteristic shrubs including prickly rose (*Rosa acicularis* Lindl.) saskatoon (*Amelanchier alnifolia* Nutt.), beaked hazelnut (*Corylus cornuta* Marsh.), and western snowberry (*Symphoricarpos occidentalis* Hook.). Commercial trembling aspen forest stands in the area typically originated in the early 1900s and have a relatively high crown density. Arable fields were planted with annual crops including oats, wheat, and canola, and were subject to various management practices. Native grasslands were characterized by a mixture of shrubs, including prickly rose (*R. acicularis* Lindl.), western snowberry (*S. occidentalis* Hook.), and wolf willow (*Elaeagnus commutata* Bernh.), and graminoids, such as plains rough fescue (*Festuca hallii* (Vasey) Piper), porcupine grass (*Stipa spartea* Trin.), June grass (*Koeleria macrantha* (Ledeb.) Schultes),

**Table 1**
Locations and properties of climosequence surface soils assessed.

| Land use | Location | Latitude | Longitude | OC | TN | C:N | pH | Sand | Silt | Clay | Canadian System of Soil Science Classification[a] | World Reference Base Classification[b] | USDA Soil Taxonomy Classification[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °N | °W | – g kg$^{-1}$ – | | | | – % – | | | | | |
| Grassland | 1 | 53.293 | 108.760 | 43.8 | 4.2 | 10.3 | 5.7 | 49 | 26 | 25 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 2 | 53.321 | 108.777 | 39.0 | 4.2 | 9.2 | 7.0 | 69 | 12 | 19 | Calcareous Black Chernozem | Haplic Calcisol | Typic Calcicryoll |
| | 3 | 53.341 | 108.764 | 45.4 | 4.1 | 11.0 | 6.1 | 69 | 17 | 15 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 6 | 53.438 | 108.765 | 25.2 | 2.5 | 9.9 | 7.0 | 81 | 6 | 13 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| Forest | 1 | 53.293 | 108.763 | 53.2 | 4.3 | 12.4 | 6.3 | 31 | 57 | 12 | Orthic Luvic Gleysol | Haplic Luvic Gleysol | Typic Cryaqualf |
| | 2 | 53.319 | 108.776 | 55.8 | 5.4 | 10.4 | 5.4 | 64 | 17 | 19 | Dark Gray Luvisol | Cutanic Luvisol (Humic) | Typic Haplocryalf |
| | 3 | 53.341 | 108.765 | 55.9 | 4.2 | 13.2 | 4.9 | 63 | 19 | 18 | Dark Gray Luvisol | Cutanic Luvisol (Humic) | Typic Haplocryalf |
| | 6 | 53.438 | 108.764 | 71.3 | 4.8 | 14.9 | 5.2 | 56 | 31 | 13 | Brunisolic Gray Luvisol | Cutanic Luvisol (Abruptic) | Typic Haplocryalf |
| | 8 | 53.489 | 108.809 | 32.1 | 2.1 | 15.3 | 5.5 | 65 | 20 | 15 | Dark Gray Luvisol | Cutanic Luvisol (Humic) | Typic Haplocryalf |
| | 12 | 53.707 | 108.805 | 5.9 | 0.4 | 14.9 | 4.9 | 67 | 28 | 5 | Dark Gray Luvisol | Cutanic Luvisol (Humic) | Typic Haplocryalf |
| Arable | 1 | 53.292 | 108.770 | 36.8 | 4.0 | 9.3 | 6.7 | 57 | 26 | 17 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 2 | 53.324 | 108.786 | 27.3 | 2.9 | 9.5 | 7.2 | 66 | 21 | 13 | Calcareous Black Chernozem | Haplic Calcisol | Typic Calcicryoll |
| | 3 | 53.347 | 108.782 | 24.9 | 3.0 | 8.3 | 4.7 | 64 | 23 | 14 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 6 | 53.438 | 108.773 | 60.7 | 5.4 | 11.3 | 6.1 | 53 | 30 | 18 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 8 | 53.496 | 108.806 | 20.4 | 2.2 | 9.1 | 5.3 | 58 | 30 | 11 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |
| | 9 | 53.600 | 108.783 | 21.6 | 2.4 | 9.0 | 6.3 | 56 | 21 | 23 | Dark Gray Luvisol | Cutanic Luvisol (Humic) | Typic Haplocryalf |
| | 12 | 53.704 | 108.804 | 44.3 | 2.8 | 15.6 | 5.2 | 67 | 23 | 10 | Orthic Black Chernozem | Calcic Chernozem | Calcic Haplocryoll |

[a] Soil Classification Working Group (1998).
[b] IUSS Working Group WRB (2014).
[c] Soil Survey Staff (2014).