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Land use legacy regulates microbial community composition in transplanted Chernozems

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ABSTRACT

Understanding how soil fertility and current practices affect microbial function in different soils is important for the development of sound management recommendations. However, interactions of the soil matrix with topography and climate obscure these interpretations. A long-term soil quality experiment was established in 1990 at Lethbridge, AB to examine the effects of agricultural management practices on different soils transplanted to a common location to normalize for climatic and topographic influences. Transplanted soils were continuously cropped to wheat with residues removed at harvest, with and without nitrogen (N) fertilizer (0 or 60 kg N ha^{-1}). Phospholipid fatty acids (PLFA) profiling of whole communities and analysis of N-cycling functional genes in 10 of the transplanted soils sampled in 2012 revealed that soil origin and land use history had a dominant long-term impact on microbial abundance and community composition. Long-term N fertilizer application did not influence total microbial biomass, bacterial, and fungal abundance. The highest microbial biomass (ca. 25 nmol PLFA g^{-1} soil) was observed in more fertile (CC (cereal cultivated)) and RM (30 t ha^{-1} yr^{-1} manure) soils whereas the lowest biomass was found in transplanted sub-surface soils from B (6 nmol PLFA g^{-1} soil) and C horizons (8 nmol PLFA g^{-1} soil). Bacterial *amoA*, *nirK* and *nirS* community compositions were significantly influenced by N application. However, the degree of influence was mainly regulated by soil origin. Long-term N fertilization resulted in convergence of bacterial *amoA* community structure of CC and PL but not RM and DTF soils; archaeal *amoA* was not affected by N application. The reliance of the microbial community on inherent soil fertility was exacerbated by residue removal and was indicated by the strong influence of soil origin which reflected soil genesis and land use history. These findings reveal a persistent effect of soil legacy on soil microbial communities. Agricultural soil productivity can be enhanced by integrating soil history information into strategies for developing sustainable management practices.

1. Introduction

Soil microorganisms are major players of agroecosystem functions and sustainability. They contribute to soil organic matter (OM) decomposition, carbon (C) dynamics and biogeochemical cycling of soil nutrients. Changes that occur to microbial communities consequently affect soil processes (Cavigelli and Robertson, 2001). Currently, there is a growing interest in determining the best predictors of microbial community function in terrestrial ecosystems. Soil microbial abundance and community structure follow different patterns at various ecological scales; however, the key drivers behind those patterns are not fully understood. Understanding the nature of these patterns is the foundation for sustainable ecosystems management (Levin, 1992).

Microbial community composition and structure in agricultural soils are highly complex and are governed by various biotic and abiotic factors such as soil physical and chemical properties, soil management and environmental conditions. Several studies have shown the influence of agricultural management and land use changes on the presence of soil organisms or specific functional groups (Buckley and Schmidt, 2001; Allison et al., 2005; Ding et al., 2013; Cederlund et al., 2014; Hartmann et al., 2015) and Buckley and Schmidt (2003) have shown that local soil environmental factors dominantly impact microbial dynamics. Furthermore, soil chemical properties such as pH (Fierer and Jackson, 2006), organic C (OC) and total N (TN) content also affect soil microbial community structure (Girvan et al., 2003; Hartmann et al., 2015). These findings are useful in understanding the microbial functions and community composition under specific environmental conditions associate with geographic location (Wieland et al., 2001;

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Buckley and Schmidt, 2003; Drenovsky et al., 2010; Marschner et al., 2011; Philippot et al., 2013). The inability to decouple the effect of soil characteristics from confounding factors such as climate, topography and hydrology has impaired our understanding the response of different soils to management (Zvomuya et al., 2008; Olson et al., 1996).

Long-term research sites serve as "test beds" which provide the opportunity to reveal dynamics of ecosystem processes and patterns (Hobbie, 2003). A long-term field experiment in which a variety of soils were transplanted at a single site located at Lethbridge, AB, Canada on the Agriculture and Agri-Food (AAFC) research station, provided a unique opportunity to assess the effects of soil quality parameters on microbial communities by decoupling the influence of confounding factors such as climate, topography and hydrology that normally complicate inter-site comparisons of different soils (Janzen et al., 2012; Zvomuya et al., 2008; Olson et al., 1996). In 1990, 36 different Chernozems having distinct physical, chemical and biological characteristics (i.e. variable fertility levels) were transplanted to a common environmental and management condition (Zvomuya et al., 2008; Janzen et al., 2012). After 14 yr of transplantation, some convergence in C and N mineralization was observed by Zvomuya et al. (2008). We hypothesized that identical agricultural management, climatic and topographic conditions would cause convergence of the abundance and diversity of microbial communities and N-cycling functional groups (nitrifiers and denitrifiers) in different soil types. To address this hypothesis, a comprehensive survey of microbial abundance and composition was conducted, > 21 yr after transplantation of the original soils. Furthermore, the impacts of N fertilization (+/−) on overall microbial abundance and community structure in nitrifier and denitrifier communities of transplanted soils were assessed.

2. Materials and methods

2.1. Field site establishment and experimental design

The soils used in this study were obtained from the long-term transplant experimental site located at the AAFC at Lethbridge, AB, Canada (49°42′ N, 112°50′ W). The original soil characteristics of the field were classified as an Orthic Dark Brown Chernozem (Typic Boroll) with a 20 cm Ap horizon, a thin B horizon (≤10 cm) and a calcareous C horizon (Olson et al., 1996; Zvomuya et al., 2008; Janzen et al., 2012). In 1990, the original topsoil (Ap) at the site was stripped (minimizing compaction) using an excavator with 2.4 m wide shovel (Olson et al., 1996). After topsoil removal, the exposed subsoil was mainly C horizon with thin B horizon remaining in some locations. The exposed subsoil was lightly tilled (~2 cm) using a disk harrow to roughen the interphase of original subsoil and transplanted soils (Zvomuya et al., 2008). Topsoils obtained from 36 different donor sites located within 100 km radius of the AAFC experimental site were deposited on pre-prepared experimental sites. Many of the transplanted soils were topsoils (Ap/Ah horizons) from various locations at the research station; however, two transplanted soils were two sub-surface soils (B and C horizons) from adjacent locations that had experienced erosion. Transplanted soils from different management backgrounds had diverse soil physical, chemical and biological characteristics at the time of relocation (Olson et al., 1996). All the transplanted soils were classified as Chernozems. One truck-load of donor soil (8 Mg dry weight) was used for each replicate of a particular soil. Three replicates of soil were collected separately from each donor site (Janzen et al., 2012). The soils were deposited in 5 m by 6 m plots that were delineated by temporary wooden frames, which were removed after the soils from adjacent plots had been deposited (Olson et al., 1996; Zvomuya et al., 2008). The mean depth of deposition after two years (1992) of transplanting was 19 cm, with a range of 15 to 24 cm (Zvomuya et al., 2008).

The experimental design was a split plot where the main plots were arranged in a randomized complete block design with three blocks (n = 3). Transplanted soil type was used as the main plot factor with the rate of N fertilizer as the subplot factor (Zvomuya et al., 2008). Each main plot was subdivided and NH_4NO_3 was broadcasted at 0 kg N ha^{-1} (6 m by 3 m) and 60 kg N ha^{-1} (6 m by 2 m) on two subplots prior seeding each year (Zvomuya et al., 2008). Layout of the experiment design can be found in Olson et al. (1996). Beginning in 1991, the field has been continuously cropped with spring wheat (*Triticum aestivum* L.) and zero tillage has been practiced. Further, seeding and harvesting have been conducted in such a way that minimizes soil compaction. After harvesting, the remaining crop residues were swathed, baled and removed for livestock bedding (Zvomuya et al., 2008). This is a typical practice in the region where there is a high concentration of intensive beef feedlot operations that require straw bedding.

2.2. Soil selection and sampling

Among the 36 transplanted soils, 10 soils with diverse soil properties at the time of transplanting, including split plots (N^+ and N^-) were selected for investigation (i.e., 10 soil types by two N fertilizer treatments by three replicates). Both management history and soil OC and TN contents at the time of transplanting were used to select the studied soils. A summary of history of land use and soil characteristics of the selected transplanted soils for the current study is presented in Table 1. TC and TN at 1990 were measured by automated combustion (Model 1500 CNS analyzer, Carlo Erba Instruments) (Janzen and Ellert (technical report), 1999).

Soil sampling was carried out in September 2012 using an E.G. truck-mounted Giddings soil sampler, equipped with a 3.175 cm diameter sampling probe. Four soil cores were obtained from each replicate plot at a depth of 0- to 10-cm. Soil samples were homogenized and stored at 4 °C immediately after collection. The fresh soil samples were processed by sieving through a 4 mm mesh size sieve and soil gravimetric moisture contents were determined by placing 10 g of fresh

Table 1
Description and background information of transplanted soils.

Soil origin	Soil[†]	Soil zone	Soil texture	pH	Soil characteristics
Native grassland (NG)	2	Dark Brown	Sandy clay loam	6.6	Previously uncultivated soil, native grassland Ah horizon
Dryland wheat (DW)	4	Dark Brown	Sandy clay loam	6.6	Continuous dryland wheat since 1911
Cereal cultivated (CC)	8	Black	Clay loam	6.2	Highest soil inherent fertility, land was a native grassland until 1982 and continuous cereal production
Pastureland (PL)	9	Black	Clay loam	5.3	Highest inherent fertility, native pastureland
Dryland tilled fallowed (DTF)	11	Dark Brown	Clay loam	6.3	Low inherent fertility, continuous dryland tilled and summer fallowed since 1911 (uncultivated)
Irrigated tilled fallowed (ITF)	16	Dark Brown	Sandy clay loam	6.9	Irrigated tilled summer fallowed since 1911 (uncultivated)
Manured (30 t ha^{-1}) (RM)	22	Dark Brown	Clay loam	6.8	Wet manure was applied 30 tons ha^{-1} since 1973 and continuous dryland barley cultivation
Manured (90 t ha^{-1}) (HM)	23	Dark Brown	Clay loam	6.9	Wet manure was applied 90 tons ha^{-1} continuously since 1973, continuous dryland barley cultivation
B horizon (BH)	26	Dark Brown	Clay loam	6.6	Sub-surface soil from an eroded native grassland
C horizon (CH)	27	Dark Brown	Loam	7.4	Sub-surface soil from an eroded native grassland

[†] Field soil numbers assigned by AAFC, Lethbridge, AB.