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Nitrogen fertilization and tillage reversal affected water-extractable organic carbon and nitrogen differentially in a Black Chernozem and a Gray Luvisol

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ABSTRACT

Reversing land management from no tillage to conventional tillage (tillage reversal) to deal with weed infestation and accumulation of crop residue in long-term no tillage systems may dramatically alter soil carbon (C) dynamics. We studied the impact of nitrogen (N) fertilization and tillage reversal on the quantity and quality of water-extractable organic C (WEOC) and N (WEON) in the 0–10 cm soil layer in two contrasting soil types located at Ellerslie (high organic matter content) and Breton (low organic matter content) in central Alberta, Canada. We used a split-plot design with N assigned to the main plot and tillage to the subplot. Each treatment had two levels which included addition of 0 (N0) vs. 100 kg N ha^{-1} yr^{-1} (N100) N fertilizer and long-term no tillage (NT) vs. tillage reversal (TR); straw was retained on site in all treatments as part of the management regime. Our results showed that soil organic C and N storage were not affected by long-term N fertilization or tillage reversal at Ellerslie but were increased at Breton. Soil WEOC was significantly higher under N100 than under N0 at both sites. Soil WEOC was TR < NT at Breton but was not affected by tillage at Ellerslie. Soil WEON was influenced by the interaction effects of N fertilization and tillage reversal at both sites. The highest WEON concentration was in the N100–TR treatment combination (17.8 ± 1.5 and 10.5 ± 0.7 μg g^{-1} at Ellerslie and Breton, respectively). Nitrogen fertilization decreased the aromaticity of WEOC at both sites but had different effects on WEOC condensation between Ellerslie and Breton. Nitrogen fertilization increased non-aromatic compounds in WEOC and the stability of WEOC at Breton but not at Ellerslie. Neither tillage nor tillage × fertilizer interaction affected the quality of WEOC in either soil. Therefore, N fertilization was the main factor controlling the quality and quantity of WEOC in the studied soils.

1. Introduction

Water-extractable organic carbon (WEOC) and nitrogen (WEON) are important components of water-extractable organic matter (WEOM) which is considered to be the most labile and biodegradable fraction of soil organic matter (Chantigny, 2003). The dynamics of WEOM may reflect changes in the soil condition (Akagi et al., 2007). Water-extractable organic matter plays a key role in nutrient cycling in terrestrial ecosystems because all microbial uptake mechanisms require an aqueous environment (Metting, 1993). Water-extractable organic matter can provide a source of energy for microbial activities and alter soil biogeochemical processes (Hassouna et al., 2010).

Previous incubation studies showed that 10–44% of WEOM in soil solutions were microbially degradable (Kalbitz et al., 2000; Sachse et al., 2001). Qualls and Haines (1992) found rapidly and slowly degradable WEOM in soil solutions. The biodegradation of WEOM is depended on its intrinsic properties which in turn influence the formation of stable organic C in the soil (Kalbitz et al., 2003a,b,b). Controls on the WEOM quality to a large extent are still poorly understood (Kalbitz et al., 2000; Fellman et al., 2008).

In agricultural ecosystems, land management practices (e.g., tillage and N fertilization) can alter soil physical and chemical properties such as soil structure and pH. Such changes in soil properties are likely to influence the quantity and quality of WEOM. However, most work on N fertilization effects over the past decade has been focused on forest and grassland ecosystems, with little effort spent on qualifying WEOM fluxes in soils in intensively managed systems such as in agricultural soils (McDowell, 2003). Some studies report no significant effect from N fertilization (Rochette and Gregorich, 1998; Zsolnay and Görlitz, 1994), while

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others report decreases (Chantigny et al., 1999; Liang et al., 1998) or increases in WEOC after N fertilization (McTiernan et al., 2001). Those contradictory results highlight a need for improved understanding of the effect of intensive agricultural management practices on WEOM dynamics.

It is commonly accepted that C sequestration can be accomplished by changing from conventional tillage to no tillage (Bruce et al., 1999; Kahlon et al., 2013; West and Post, 2002). However, long-term no tillage management can cause problems such as accumulation of crop residues, weed infestation, nutrient stratification on the soil surface (Grant and Bailey, 1994; Baan et al., 2009) and pesticide accumulation (Baker and Saxton, 2007). Long-term no tillage may also reduce water infiltration due to surface soil compaction. Reversing no tillage to conventional tillage (tillage reversal) may be a way to deal with those problems and the possibility exists that landowners may change their mind and may opt to tillage from no tillage management. Tillage reversal (TR) can disrupt soil aggregates and expose labile or fresh organic matter that was once protected with aggregates, making it susceptible to microbial decomposition (DeGryze et al., 2004; Grandy and Robertson, 2007; Six et al., 1999) which may change the quantity and quality of WEOC. Tillage reversal may also result in the incorporation of fresh crop residue into the soil profile which would also change the quantity and quality of WEOC. Since only few studies have focused on tillage reversal practices (Shahidi et al., 2014), the influence of tillage reversal on C sequestration is poorly understood. Moreover, the interaction between various agricultural management practices such as N fertilization and tillage management make the prediction of the cumulative impact of these activities on the quality and quantity of WEOC even more complicated.

We studied the dynamics of WEOC and WEON after long-term (34 years) N fertilization and 4–5 years of tillage reversal (after about 30 years of no tillage) during the growing season on two different soil types (Orthic Black Chernozem at Ellerslie and Orthic Gray Luvisol at Breton, based on the Canadian system of soil classification) within a similar ecological region. We hypothesized that N fertilization and tillage reversal will increase WEOC and WEON concentrations and decrease the stability of WEOC. The objective of this study was to assess the effects of N fertilization and tillage reversal on the storage of soil C and N, and the quality and quantity of soil WEOM.

2. Materials and methods

2.1. Field sites and soil sampling

Soil samples were collected from the long-term Tillage–Straw–Nitrogen Plots near Ellerslie (53°25′N, 113°33′W; elevation 692 m), classified as an Orthic Black Chernozem (Typic Cryoboroll) of the Malmo silty clay loam series, and Breton (53°07′N, 114°28′W; elevation 830 m), classified as an Orthic Gray Luvisol (Typic Cryoboralf) of the Breton loam series. The Black Chernozem has a higher soil fertility and better soil structure than the Gray Luvisol (Singh and Malhi, 2006). Both sites are located in Alberta, Canada. These two soils are ~70 km apart but represent two major and distinctly different soil types found in north–central Alberta.

The descriptive data for both soils are shown in Table 1, which was based on data published in Nyborg et al. (1995) and Malhi et al. (2011a,b); Malhi et al. (2011a,b). The mean air temperature from May to August in 2013 was 13.9 °C in Ellerslie area and 13.6 °C in Breton area. The mean annual precipitation in 2013 was 452 mm at Ellerslie and 555 mm at Breton.

Long-term experiment plots were established at each site in 1979 using the same experimental design (Nyborg et al., 1995). Initially, the plots were planted to barley (*Hordeum vulgare* L.) monoculture from 1983 to 1996 (Solberg et al., 1998). After 1996, barley was rotated with other crops include spring wheat (*Triticum aestivum* L.: 1997, 1998 and 2006), canola (*Brassica napus* L.: 1999, 2003 and 2007), triticale (*X. triticosecale* Wittmack: 2000, 2004 and 2008), or pea (*Pisum sativum* L.: 2001, 2005 and 2009, with no N fertilizer applied to pea). In 2009, each long-term no-till plot (with or without N fertilization) was split into 2 equal subplots (6.85 m × 1.37 m). Half of each of the long-term no-till plot was firstly subjected to tillage reversal (TR) on June 3, 2009 for the Black Chernozems and on June 4, 2010 for the Gray Luvisol (Shahidi et al., 2014). The other half of the no-till (NT) subplots were not cultivated, except for the disturbance caused by the plot seeder used each spring. The TR subplots were tilled each spring prior to seeding using a rotary tiller to a depth of about 8 cm. In both NT and TR subplots, urea was mid-row banded. Phosphorus (20 kg P ha^{-1}) was applied with seed. Therefore, the experimental design of this study was a split-plot design with the whole plots (N fertilization, N0 vs. N100 kg N ha^{-1} yr^{-1}) arranged completely randomized in each of four blocks (4 replicates) with tillage (NT vs. TR) as subplots.

Table 1
Descriptive characteristics of surface soils (0–15 cm) at Ellerslie and Breton at the time of experiment setup (Nyborg et al., 1995,b; Malhi et al., 2011a,b)

Site	Ellerslie	Breton
Total soil organic carbon (g kg^{-1})	56.4	13.8
Total nitrogen (g kg^{-1})	4.9	1.2
C:N ratio	11.5	11.5
Clay content (%)	36.0	22.0
Soil pH	6.0	6.6

The first soil sampling was conducted within one week after N application in May 2013. After that, soil samples were collected monthly until the end of the growing season (August 2013). On each sampling, seven soil cores (3 cm diameter) were collected from 0 to 10 cm depth (Ap horizon) of each plot and composited. In the laboratory, visible roots, earthworms and straw residue were removed. The moist soil was passed through a 2 mm sieve. A subsample was taken from each soil sample and air-dried for a week for determining soil total organic C (TOC) and TN. The remaining fresh soil was frozen until further analyses.

2.2. Soil total organic C and total N and WEOM extraction

The air-dried soil samples were used to determine soil TOC and TN content using a Carlo Erba NA 1500 elemental analyzer (Carlo Erba Instruments, Milan, Italy).

Organic matter was extracted from fresh soil samples using deionized water according to a modification of the procedure of Roehm et al. (2009). Fresh soils were added with ultrapure water (1:2, w:w) and shaken for 2 h on a reciprocal shaker at 20 °C. After centrifuged at 12,500 × *g* on a high speed centrifuge (Thermo IEC MultiRF) for 20 min, the supernatant was filtered with a 0.2 μm syringe filter (Fisherbrand, Nylon) to remove microbial biomass (Fellman et al., 2008; Xu et al., 2013). The filtrates were then analyzed for WEOC and total water-extractable N by a Shimadzu TOC-V CSH/CSN analyzer (Shimadzu Corporation, Kyoto, Japan). Nitrate in the extract was determined by the method of Miranda et al. (2001) at room temperature with a UV spectrometer (Thermo Spectronic Genesys 10S) in 1 cm quartz cuvettes. Ammonium in the extract was determined with the indophenol blue method with the same UV spectrometer (Keeney and Nelson, 1982). The WEON was then calculated by subtracting mineral N (nitrate plus ammonium) from total water-extractable N.

The chemical characteristics of WEOC were determined through measurement of ultraviolet (UV) absorbance and fluorescence spectroscopy. UV absorbance at 280 nm was used to estimate