Geoderma 306 (2017) 40–49

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Bulk optical characterization of dissolved organic matter from semiarid wheat-based cropping systems

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ARTICLE INFO

Keywords:
Semiarid soil
Winter wheat
Conservation agriculture
Excitation emission matrix
Parallel factor analysis

ABSTRACT

Dissolved organic matter (DOM) plays a critical role in the cycling of nutrients and long-term agricultural sustainability. The composition of DOM in soil is likely altered due to management, yet there is limited knowledge on the effect of long-term cropping on DOM chemical character. Here, we characterized water extractable DOM composition along a gradient of soil organic carbon (SOC) affected by differing cropping and tillage intensity in a semiarid climate of the northern Great Plains, USA. Soil samples (0–10, 10–20, 20–30 cm) were collected from conventional till-fallow winter wheat (*Triticum aestivum* L.; F_{till}-W), no-till spring pea/oilseed-wheat (*Pisum sativum* L.; P_g/O-W), and no-till continuous wheat (W-W) fields, and analyzed using UV/Vis absorbance and excitation-emission matrix fluorescence spectroscopy. The concentration of DOM decreased with depth and was significantly greater ($P < 0.05$) under W-W or P_g/O-W than F_{till}-W. The absorbance at 254 nm (Abs_{254}), a proxy for DOM aromatic nature, indicated that aromaticity decreased with depth and lower biomass-C inputs (i.e. W-W ≥ P_g/O-W ≥ F_{till}-W). Multidimensional parallel factor (PARAFAC) analysis revealed humic-like (C1, C2), monolignol-like (C3), and protein/tannin-like (C4) components with varying fluorescence intensities as a function of cropping system and soil depth. DOM humification, indicated by the humification index (HIX), increased significantly with depth ($P < 0.05$) and was higher for F_{till}-W (2.95) than W-W (2.61) or P_g/O-W (2.28). Overall, DOM became depleted of plant-derived constituents and was enriched by more decomposed, condensed substances in F_{till}-W, as compared to W-W or P_g/O-W soils. DOM composition is strongly affected by cropping intensity and such changes are important drivers controlling SOC accretion in arable soils.

1. Introduction

Dissolved organic matter (DOM) is the most dynamic and reactive component of soil organic carbon (SOC) in terrestrial ecosystems (Bolan et al., 2011). Although this pool accounts for a minimal portion of SOC (i.e. < 0.5–1%), DOM components exert a critical control over the biogeochemistry of soils by serving as a substrate for microbial activity and influencing the availability of plant nutrients and metal ions (Kalbitz et al., 2000; Bolan et al., 2011). The occurrence of DOM in soil is also critical to regulate both CH_4 and N_2O production (Bolan et al., 2011). Furthermore, terrestrial DOM is an important source of organic matter in freshwater ecosystems, affecting drinking water supplies through eutrophication and nutrient runoff (Wilson and Xenopoulos, 2009).

DOM is a heterogeneous mixture of plant and microbial derived constituents with varying degrees of reactivity (Bolan et al., 2011). Chemically, DOM can be conceptualized in terms of biologically active and stable humified fractions. Biologically active compounds are both aliphatic (i.e. amino acids, carbohydrates) and aromatic constituents (i.e. fulvic acids) of low molecular weight rapidly metabolized by soil microorganisms (Vázquez et al., 2016; Pan et al., 2017). Contrarily, humified pools are complex aromatic substances derived from decomposing lignocellulosic polymers (Stevenson, 1994; Vázquez et al., 2013) that can exhibit strong resistance against biodegradation (Marinari et al., 2010).

Several factors affect the quantity and quality of SOC and the water extractable DOM fraction in arable soils (Kalbitz et al., 2000). Besides soil temperature and water content (Burke et al., 2008), management practices (i.e. tillage, crop rotation) can influence SOC occurrence by (i) modifying soil physical structure and aggregation (Bongiovanni and Lobartini, 2006; Dieckow et al., 2009), (ii) changing the amount and quality of biomass-C inputs returned to the system (Chantigny, 2003;

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http://dx.doi.org/10.1016/j.geoderma.2017.06.029
Received 27 May 2017; Received in revised form 27 June 2017; Accepted 28 June 2017

Table 1
Selected physical and chemical properties of soil at the experimental site.

Soil depth	Texture			BD[a]	CEC[b,g]	EC[c,h]	pH[i]	IC[d]	SOC[e,j]	TN[f,j]	C:N
	Sand	Silt	Clay								
cm	g kg^{-1}	g kg^{-1}	g kg^{-1}	g cm^{-3}	cmol$_c$ kg^{-1}	dS m^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	
0–10	173	613	214	1.16	18.41	0.11	6.28	0.58	13.0	1.3	9.7
10–20	163	606	231	1.34	17.97	0.07	6.59	0.87	9.6	1.1	8.7
20–30	158	630	212	1.43	19.42	0.05	7.22	1.64	7.7	0.9	8.5

[a] BD = bulk density.
[b] CEC = cation exchange capacity.
[c] EC = electrical conductivity.
[d] IC = inorganic carbon.
[e] SOC = soil organic carbon.
[f] TN = total nitrogen.
[g] Unbuffered 0.2 M NH_4Cl.
[h] 1:2 soil:water extract.
[i] 1:1 soil:water extract.
[j] LECO dry combustion (LECO Corp., St. Joseph, MI). Data taken from Engel et al. (2017).

Vázquez et al., 2016), and (iii) altering mineralization and humification pathways of plant residues in soil (Kalbitz et al., 2000; Vázquez et al., 2016). No-tillage (NT) management is often claimed to promote SOC accretion in surface soil (i.e. 0–30 cm) (Dieckow et al., 2009; Norton et al., 2012). However, the effect of long-term cropping intensity on SOC quality is not clear and still under debate; management practices may differentially affect SOC composition depending on site-specific environmental factors, such as climate and soil type (Embacher et al., 2007; Borisover et al., 2012).

In the northern Great Plains of North America, conversion from native semiarid shortgrass steppe to dryland wheat-fallow (W-F) cropping has resulted in severe soil erosion and a net loss of nutrients (DeLuca and Zabinski, 2011). A century of cultivation has decreased surface SOC and associated C fractions by ~50–60% (Norton et al., 2012; Hurisso et al., 2013). Recently, NT management has become increasingly popular, currently comprising 60% of dryland agriculture in this region (Hansen et al., 2012). With NT management, precipitation storage has improved and led to greater cropping system intensification with legume and/or oilseed crops being grown in rotation with wheat (Miller et al., 2015; Chen et al., 2015). More diverse and intensified NT systems have prompted SOC recovery through increased biomass-C inputs and minimal disturbance of soils. Several reports have documented higher SOC contents under NT annual cropping than conventional tillage (CT) with W-F systems (reviewed by Watts et al., 2011 and Collins et al., 2012). A recent study by Engel et al. (2017) quantified SOC levels among eight management systems in southern Montana, including CT fallow-wheat (F_{till}-W), NT spring pea/oilseed-wheat (P_g/O-W) and NT continuous wheat (W-W). After 10 yr, cumulative SOC stocks (0–30 cm) for NT W−W, NT P_g/O-W and F_{till}-W systems, average of two N levels, were equivalent to 38.4, 37.9, and 33.7 Mg C ha^{-1}, respectively. The degree to which SOC accumulated in soil was directly related to biomass-C inputs, particularly root and/or root-derived C. Engel et al. (2017) report SOC maintenance levels at 2.6 Mg ha^{-1} yr^{-1} of shoot + root + rhizodeposit C, or 7.0 Mg ha^{-1} yr^{-1} of net primary productivity (NPP), with accretion or loss occurring above or below these thresholds, respectively.

Accumulation of SOC after 10 yr of NT annual cropping (Engel et al., 2017) suggests recovery trends towards improved soil quality. Within this context, some differences in SOC composition were expected. The objective of this study was to characterize the chemistry of SOC following a continuum from minimally disturbed soils with high biomass-C inputs (i.e. NT annual cropping) to more strongly degraded fields (CT W-F). We extracted and further analyzed DOM from soil samples (0–30 cm) collected in 2012 along F_{till}-W, P_g/O-W and W-W fields (Engel et al., 2017) by combined use of non-destructive spectroscopic techniques such as UV/Vis absorbance and excitation emission matrix fluorescence spectroscopy (EEMs). We hypothesized that (i) additional biomass-C inputs under NT annual cropping (P_g/O-W, W-W) would increase plant-derived DOM constituents when compared to F_{till}-W, (ii) such changes would be associated with increasing SOC sequestration rates, and (iii) the influence of cropping systems on DOM properties is attenuated from surface soil to subsoil layers.

2. Materials and methods

2.1. Experimental site and study design

The soil analyzed in this study came from a long-term cropping system study established at Montana State University's Arthur H. Post Agronomy Research Farm, located 10 km west of Bozeman, Montana, USA (45° 40′ N, 111° 09′ W, elevation 1450 m). The location is characterized by a semiarid cold climate with annual precipitation of 411 mm and a mean annual temperature of 6.7 °C (Western Regional Climate Center, 2014). The soil is a Mollisol-type, classified as an Amsterdam silt loam (fine-silty, mixed, superactive, frigid Typic Haplustolls), generally deep and well-drained, and derived from loess-like deposits mixed with volcanic ash (Soil Survey Staff, 2013). Selected soil properties to a depth of 30 cm are presented in Table 1. The field study consisted of eight management systems replicated four times in a randomized complete block design, previously described by Engel et al. (2017). The water extractable DOM was characterized in three of the eight cropping systems, including F_{till}-W, P_g/O-W and W-W managed at a high N fertility level, and where large differences in SOC mass accretion were observed.

2.2. Soil sampling and processing

Soil sampling occurred in September 2012, or 10 yr after initiation of the field trial, using a truck mounted hydraulic probe. Triplicate soil cores (5 cm dia.) were collected to a depth of 30 cm from each plot, separated into three depth increments (0–10, 10–20, and 20–30 cm) and composited per depth. The composite core samples were placed in plastic-lined bags, dried (50 °C), and then crushed to pass through a 2-mm sieve. A subsample of the sieved material was then separated, and all identifiable crop residue material including roots were removed by hand-picking with tweezers prior to its analysis.

2.3. Dissolved organic matter

Soil (50 g) was added to an acid-washed (10% HCl), pre-combusted (425 °C, 4 h) 250-mL Erlenmeyer flask with 100 mL of ultrapure Milli-Q® water (≤ 18.2 MΩ cm^{-1}). The flasks were shaken (15 min,