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Labile soil organic carbon and nitrogen within a gradient of dryland agricultural land-use intensity in Wyoming, USA

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ABSTRACT

Tillage in dryland winter wheat (*Triticum aestivum* L.)–summer fallow cropping systems of the central High Plains, USA, has caused significant erosion and loss of soil organic matter (SOM), underscoring the need for more sustainable practices on marginally-productive semiarid lands. Conversion to no-till (NT) wheat–fallow or perennial grass–legume cover, as in the Conservation Reserve Program (CRP), provides viable alternatives to tillage-based wheat–fallow practices. However, the overall impact of transitioning on soil biogeochemistry is not fully understood. Labile SOM pools were determined on soil cores (0–120 cm) collected in July 2011 from five unfertilized fields that spanned a gradient in disturbance associated with land-use practices: a more intensively tilled wheat–fallow ('historic', HT) than a conventional (CT) wheat–fallow with limited herbicides combined with tillage, NT wheat–fallow that exclusively used herbicides for ≥10 years, formerly cultivated HT wheat–fallow planted to grass–legume mixture as in the CRP for 7 years, and native prairie (NP) with no history of agricultural disturbance. Significant differences in microbial biomass C (MBC), potentially mineralizable C (PMC) and nitrogen (PMN) were largely confined to the surface soil (0–30 cm), following the order NP > CRP > all wheat–fallow systems. When expressed on a per soil organic C (SOC) basis, both MBC and PMC followed the order CRP > NP > all wheat–fallow systems. In contrast, when normalized by total soil N (TN), PMN was higher in HT and CT soils than in other soils (NT, CRP, and NP). MBC and PMC were positively correlated with SOC whereas PMN, soil pH, and electrical conductivity (EC) showed a negative relationship with SOC. These results suggest more efficient conservation of SOM under perennial grass–legume system than NT wheat–fallow rotation. We suggest that cessation of tillage alone may not be sufficient for the recovery of labile-pool SOM degraded through long-term cultivation in the absence of inputs for soil fertility renewal.

1. Introduction

Historically, agricultural production in the prairie-dominated semiarid regions of the US Great Plains began with intensive tillage with no inputs to maintain soil fertility (DeLuca and Zabinski, 2011; DuPont et al., 2010; Huggins et al., 1998). Farmers received relatively high crop yields in the first few years following the conversion (Glover et al., 2010). However, plowing of native prairies caused a rapid decomposition of native soil organic matter (SOM) ultimately leading to dramatic reductions in native soil fertility and therefore crop yields, especially in marginally productive semiarid agroecosystems.

Most of the loss in SOM following conversion of perennial-dominated native prairies to annual row-crop production is attributed to (1) a loss of easily decomposable, labile-pool SOM (DeLuca and Keeney, 1993; Huggins et al., 1998), (2) low quantity and quality of crop residue and belowground root inputs (DuPont et al., 2010; Glover et al., 2010; Guzman and Al-Kaisi, 2010), and (3) a tillage-caused loss of physical protection to SOM through degradation of soil aggregation and therefore enhanced SOM decomposition (Six et al., 2000). In the central High Plains of the US, dryland cultivation of winter wheat–fallow rotation is the most commonly used cropping system (Hansen et al., 2012; Lyon and Peterson, 2005; Nielsen and Vigil, 2010). Many farmers have traditionally relied on the extensive use of mechanical tillage as the only form of weed control (hereafter referred to as 'historic' practice, HT), or sometimes on limited herbicides combined with tillage (hereafter referred to as 'conventional' practice, CT). Unfortunately, several decades of continuous wheat–fallow cropping practice, particularly under an intensive tillage regime that removes physical protection to SOM, has led to a loss in near surface (0–30 cm depth) SOM (Halvorson et al., 2002; Lyon and Peterson, 2005; Norton et al., 2012), including a loss of soil profile water associated with the tillage operations (Farahani et al., 1998; Hansen et al., 2012; Nielsen and Vigil, 2010). Doran et al. (1998), for instance, reported a 32% soil organic C (SOC) loss from the surface 0–30 cm depth within 27 years following winter wheat–fallow cropping in western Nebraska.

The expanding use of herbicides, improved crop varieties, and direct seeding methods enabled widespread adoption of conservation tillage

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practices, such as no-till (NT) farming (Conant et al., 2007; Lal, 2008; Sanford et al., 2012). The resulting increase in yield and residue production, along with decreases in soil disturbance, is also thought to increase crop residue contribution to SOC (Conant et al., 2007; Lal, 2008). The frequency of fallow has been greatly reduced in dryland production systems of the US Great Plains due to water conservation with NT management, which enabled intensification of crop rotation, such as wheat–corn/millet–fallow (Farahani et al., 1998; Halvorson et al., 2002; Hansen et al., 2012; Nielsen and Vigil, 2010). Intensification of crop rotation is also a key aspect to the observations of increased SOC levels, because it takes advantage of the improved water capture and storage during fallow potentially leading to greater biomass production and may therefore increase organic C input to the soil (Bowman et al., 1999; Halvorson et al., 2002). However, it is not well understood how SOC changes with NT in the absence of intensified crop rotation, such as wheat–fallow (i.e. only one crop in every 2 years system).

Intensive tillage as in the HT and CT practices combined with strong and frequent winds in the central High Plains (Hansen et al., 2012) creates a great potential for wind erosion. This has led to the conversion of some dryland cropland back to perennial grass cover beginning in the 1985 through the USDA's Conservation Reserve Program (CRP) (Burke et al., 1995). Despite the widespread adoption of this program throughout the region and its great potential for SOC storage and ecosystem recovery (Baer et al., 2010; Norton et al., 2012; Sherrod et al., 2005), little is known about the recovery of labile-pool SOM from long-term cultivation following establishment of perennial grass–legume cover in Wyoming.

Here we report measures of soil profile labile (active)-pool SOM, including microbial biomass C (MBC), potentially mineralizable C (PMC) and nitrogen (PMN) from unfertilized fields that spanned a disturbance intensity gradient associated with land-use practices ranging from intensively tilled, no-fertility input wheat–fallow systems to perennial grass–legume cover. The majority of SOM is in forms that mostly turnover on the order of decades and centuries (Parton et al., 1987), and may therefore take several years to detect the recovery of SOC and N. Several previous studies demonstrate that labile C pools recover in shorter time frames than total SOC (e.g. Carpenter-Boggs et al., 2003; Dou et al., 2008; Sherrod et al., 2005). Therefore, by measuring labile-pool SOM, which turns over on an annual basis (i.e. shorter turnover time), we expected to detect early recovery trends following cessation of tillage and establishment of perennial cover. For this study we used a similar space-for-time substitution approach as that of Ihori et al. (1995), Burke et al. (1995) and Norton et al. (2012), in that a native mixed-grass prairie (hereafter referred to as "native prairie", NP) with no history of agricultural disturbance was used to provide a benchmark for pre-agriculture soil properties due to the absence of temporal data. Our overall hypothesis was that soils beneath NT wheat–fallow and CRP perennial grass–legume cover would exhibit greater recovery of labile-pool SOM relative to tillage-based wheat–fallow practices (HT and CT), especially in near surface layers of soil profile, because soils under NT management and CRP cover experience less disturbance.

2. Materials and methods

2.1. Site description

We sampled soils from five experimental fields maintained by the University of Wyoming Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, WY (42°5′ N, 104°23′ W, elevation 1314 m). All of these fields had the same parent material and were located in close proximity (within 3.5 km) with similar landscape position and soil type according to the USDA's Natural Resources Conservation Service (Soil Survey Staff, 2012). Soils at all five fields were confined to a Mitchell series (coarse-silty, mixed, superactive, calcareous, mesic Ustic Torriorthents) under the US Soil Taxonomy (Soil Survey Staff, 2012). These are relatively deep, well-drained soils developed from silty eolian deposits and/or silty alluvium derived from sedimentary rock with slopes ranging between 0 and 6%. Annual precipitation at this site averages 356 mm, of which approximately 75% is received from April through July.

2.2. Land-use practices

Until the initiation of SAREC, this area belonged to landowners and was first cultivated with dryland winter wheat–fallow rotation using either tillage alone (HT) or a combination of tillage and limited application of herbicides (CT) to control weeds. The HT wheat–fallow experienced greatest soil disturbance associated with tillage operation (≥6 passes year^{-1}) compared with CT wheat–fallow that experienced 3 to 4 passes per year. Tillage in both HT and CT practices was done with a Krause tandem disk followed by Sunflower fallow king to a depth of 20 cm for more than 60 years. This period of continuous cultivation is thought to reduce soil C and N contents to lower equilibrium levels (Mann, 1986). This study was conducted to evaluate the recovery of labile-pool SOM degraded through long-term cultivation by converting tillage-based wheat–fallow (HT) to NT wheat–fallow or back to perennial grass–legume cover, and using native prairie (NP) that had no history of agricultural disturbance to provide a reference of soil properties prior to cultivation. Conversion from HT wheat–fallow to NT wheat–fallow was implemented in 2002, after the University of Wyoming procured this area for research and education purposes. The NT wheat–fallow rotation experienced only minimal soil disturbance during planting, and exclusively used herbicides for weed control both in the wheat and fallow phases. The three wheat–fallow practices (HT, CT, and NT) evaluated in our study received no input of fertilizers.

In 2005, perennial grass–legume cover was established by planting pubescent wheatgrass (*Agropyron trichophorum*) and alfalfa (*Medicago sativa*) on formerly cultivated HT wheat–fallow field as is the case in CRP (e.g. Baer et al., 2010). For clarity purposes we will use the term 'CRP' when referring to the mixed planting of pubescent wheatgrass and alfalfa. The CRP field had never been grazed by domestic livestock, nor received any input of fertilizers since establishment, whereas the native prairie is grazed yearly during late summer through early fall, with 0.19 animals ha^{-1}. Vegetation composition at our NP field is dominated by C_3 grasses including wheatgrass (*Elymus lanceolatus*) and needle-and-thread (*Hesperostipa comata*) as well as C_4 grasses such as blue grama (*Bouteloua gracilis*), with less common non-native annual grasses (*Bromus japonicus* and *Bromus tectorum*) interspersed throughout the dominant matrix species.

2.3. Soil sampling

Soil sampling occurred in July of 2011. Within each field, five sampling locations were selected based on similarities and uniformity in topography and soil type; each sampling location was geo-referenced with GPS. All fields but the NP were approximately 0.22 ha each, and the distance between two adjacent sampling locations was 18.3 m; in the NP field, which was approximately 50 ha, two adjacent sampling locations were separated by 100 m. Each of the five sampling locations per field was designated as "pseudoreplicates" for statistical purpose ($n = 5$). At each sampling location, triplicate soil cores (5 cm diameter) from 0 to 120 m depth were extracted using a hydraulic soil probe (Giddings Machine Co., Windsor, CO) and each core was separated into four depth increments (0–30, 30–60, 60–90, and 90–120 cm). The three cores that represented each sampling location were composited into a single representative sample. In the cultivated fields (HT, CT, and NT), soils were collected from adjacent strips in wheat and fallow phases. Samples were placed in separate polyethylene bags, kept in a cooler with frozen ice packs and transported to the laboratory. We recognize that our study design lacks true field replication due to physical space limitations. Nonetheless, we believe that our sampling design is adequate for comparative purposes among our land-use practices,