Development of the soil organic carbon profile in prairie soils

Introduction

In 1935, Weaver and colleagues first observed that while the upper 15 cm of a tallgrass prairie soil profile contained seventy percent of the profile’s root and rhizome biomass, it only contained forty percent of the profile’s soil carbon (C). Roughly 100 years after continued cultivation of the prairie soils in the Midwestern US, this distribution of SOC persists (CITE). Much of the loss of SOC near the soil surface and the retention of SOC at depth can be attributed to a gradient of soil temperature and moisture that creates more favorable conditions for decomposition near the soil surface. However, these factors are not always able to account for differences in C input vs. C retention (CITE). In this paper, we study the development of a restored prairie root C pool and a maize root C pool to examine how root inputs, depth, and the interaction of the two contribute to the vertical distribution of SOC.

Prairie soils make up some of the most productive soils in the world, in part because of the large amount of C they contain. Soils store a lot of the world’s carbon. Maintaining or restoring C in the soil is important, but we lack the understanding of how to do this. Cultivation has resulted in large losses of C from the soil profile.

Much of what we know about decomposition in prairie soils comes from litterbag or laboratory incubation studies. These fail to capture the effect of depth on

Most SOC is derived from roots, especially deeper in the profile. Some C moves through the profile as DOC, but this C is generally labile and quickly enters microbial C pools. How do we currently think SOC forms?

Changes in the SOC profile after cultivation.

Materials and Methods

Site Conditions and Experimental Design

We conducted the experiment in Boone County, IA, USA on the Iowa State University Agronomy and Agricultural Engineering Research Farm (41°55′N, 93°45′W). Soils at the site were primarily Webster silty clay loam (ﬁne-loamy, mixed, superactive, mesic Typic Endoaquoll) and Nicollet loam (ﬁne-loamy, mixed, superactive, mesic Aquic Hapludoll). The 60-year mean growing season precipitation 11 km from the site was 720 mm. Prior to initiation of the ﬁeld experiment in 2008, the site was used for maize and soybean production and was planted with soybean in 2007. Soil sampling to 15 cm in November 2007 indicated mean soil pH was 6.7, mean organic matter concentration (via dry combustion analysis with a conversion factor of 1.724 from total carbon to organic matter [Schumacher, 2002]) was 51 g kg-1, mean extractable phosphorus concentration (via Bray-1 procedure) was 11 mg kg-1, and mean extractable potassium (via Mehlich-3 procedure) was 141 mg kg-1.

Experimental plots were 27 m x 61 m and were arranged as a spatially balanced complete block design (van Es et al., 2007) with four replicates of three treatments – continuous maize, reconstructed prairie, and N-fertilized reconstructed prairie. Measurements were made in 2010 and 2011, during the third and fourth years after the experiment was established. Because the prairie treatments discussed here were components of a larger cropping-systems experiment, P and K were added in May 2008 to all treatments to ensure that sufficient P and K were available for annual-crop growth. Phosphorus was added at a rate of 78 kg P2O5 ha-1 (34 kg P ha-1). Potassium was added at a rate of 146 kg K2O ha-1 (122 kg K ha-1). In 2009, P and K were added to the maize treatment at rates of 112 kg P2O5 ha-1 (49 kg P ha-1) and 112 kg K2O ha-1 (94 kg K ha-1), respectively.

Both prairie treatments were sown on 19 May 2008 with the same custom seed mix obtained from Prairie Moon Nursery (Winona, MN, USA) that contained 31 species, including C3 and C4 grasses and leguminous and non-leguminous forbs (Table S1). All species were perennial and sourced from within 240 km of the experiment site. The composition of the seed mix by weight was 12% C3 grasses, 56% C4 grasses, 8% legumes, and 24% non-leguminous forbs. A detailed description of the prairie plant community compositions can be found in Jarchow and Liebman (2013). The fertilized prairie treatment received no fertilizer in 2008 (the establishment year), and was fertilized at a rate of 84 kg N ha-1 year-1 in all subsequent years. Plots were fertilized during very early growth on 29 March 2010 with ammonium nitrate (34% N) and 11 April 2011 with urea ammonium nitrate (32% N). This fertilizer rate was chosen because it was similar to the maximum rate of pre-planting N fertilization recommended for maize (Blackmer et al., 1997) and the expected N removal in the harvested biomass of perennial grasses grown in the area (Heggenstaller et al.,2009).

The maize hybrid used (Agrigold 6325 VT3) had a 104-day relative maturity and transgenes for glyphosate resistance, maize borer (*Ostrinia nubilalis*) resistance, and maize rootworm**(***Diabrotica* spp.) protection. Maize was planted following standard practices (Abendroth et al., 2011) in rows spaced 76 cm apart at 79,500 seeds ha-1 on 6 May 2010 and 82,500 seeds ha-1 on 11 May 2011. In 2010, maize received 87 kg N ha-1 at planting and an additional 36 kg N ha-1 on 17 June; in 2011, maize received 87 kg N ha-1 at planting and an additional 56 kg N ha-1 on 29 June. Rates of N added after planting were based on results of late-spring tests of soil nitrate-N concentration (Blackmer et al., 1997). All N was applied as urea-ammonium nitrate (32% N). An unfertilized maize treatment was not included in the experiment because the effects of N fertilizer on maize are well known (Cerrato and Blackmer, 1990; Sawyer et al., 2006; Kveryga et al., 2009).

Data Collection

*Soil Collection*

Soil cores were taken to 1 m depth in all plots each year over a six year period using a hydraulic soil probe (Giddings Machine Co., Windsor, CO, USA) after all crops were harvested. Sampling occurred by replicate block from 31 October-25 November 2008, 9-11 November 2009, 25-28 October 2010, and 28-31 October 2011, 16-17 October 2012 and 7-11 October 2013.

In 2008, two cores were taken per plot. A 0-30 cm fraction was taken with a 10.2 cm internal diameter soil probe; the 30-100 cm fractions of the cores was taken within the same hole as the 0-30 cm fraction, but with a smaller soil probe. In Blocks 1 and 4, the internal diameter of the core was 6.0 cm. In Blocks 2 and 3, the internal diameter of the core was 5.2 cm.

In 2009 and 2010, four cores were taken per plot. The 0-30 cm fraction of the cores were taken with a 10.2 cm internal diameter soil probe; the 30-100 cm fraction of the cores were taken directly below the 0-30 cm fraction with a 5.1 cm internal diameter probe. In 2011-2013, four cores were taken per plot, and the entire core was taken with a 5.1 cm internal diameter probe.

Soil cores were ultimately divided into three or five depth increments. In 2008, depth increments were 0-30 cm, 30-60 cm, and 60-100 cm. In 2009-2013 depth increments were 0-5 cm, 5-15 cm, 15-30, cm, 30-60 cm, and 60-100 cm. Following division and extraction from the field, soil cores were stored at 5°C until processing was initiated.

*Root Collection*

Root extraction from the soil began by washing the soil samples in wire mesh tubes (0.28 mm mesh) for 3 h in an elutriator (Wiles et al., 1996). Roots were removed from the remaining soil by suspending the air-dried sample in water and collecting the roots, which floated, with sieves followed by manually removing any remaining non-root material that was present in the samples. Any plant crowns that were present in the samples were removed and were not considered to be root biomass. Roots were then dried at 70°C for at least 4 h before being weighed. All above- and belowground biomass samples were ground to 2 mm with a centrifugal mill and concentrations of C and N were determined by combustion analysis in a CN analyzer (LECO Corporation, St. Joseph, MI) at the Soil and Plant Analysis Laboratory at Iowa State University (Ames, IA, USA).

Each year before roots were washed, 60-100 g of root-free soil was removed from each depth increment, air-dried, and archived in airtight containers at room temperature. In 2008 and 2013, this soil was ground on a roller-mill and organic C content was determined by first removing inorganic C with an acid treatment followed by catalytic oxidation and CO2 measurement with NDIR in an Elementar TOC Cube at Brookside Laboratories, Inc. (New Bremen, Ohio).

In addition to annual measurements of the root pool, belowground biomass in 2010 and 2011 was measured with an in-situ growth core approach (Neill, 1992) to capture only those roots growing within the measurement year. After fall harvest in 2009 and 2010, eight 10.2-cm-diam soil cores were taken to 30 cm depth in each plot and brought to the laboratory. Holes created in the field were held open during the winter by capped 10.2 cm PVC piping. In the laboratory, cores were divided into 10 cm sections and virtually all roots were removed by hand. At the end of winter while plants were still dormant, the root-free soil was returned to its original location in the field in 10 cm depth increments. Soil was packed to imitate the surrounding bulk density, approximately 1.4 g cm-3. Root-free zones were located randomly within prairie plots and at 20 cm from maize rows. Eight root-free areas were situated within each plot, allowing duplicate sampling at four time points throughout the growing season. Two 4-cm-diam soil cores were taken within each 10.2-cm-diam root-free area to a 30 cm depth at each root sampling date. Bulk soil was washed from the roots with water using a soil elutriator (Wiles et al., 1996), roots were dried at 60° C for 24 hours, non-root biomass was removed from the roots by hand, and roots were weighed.

After drying, all the above- and belowground plant samples were ground to a fine powder (<1 mm) with a centrifugal mill and concentrations of carbon (C) and N were determined by combustion analysis at the Soil and Plant Analysis Laboratory at Iowa State University (Ames, IA, USA).

Data Analysis