Soil organic matter dynamics and land use change at a grassland/forest ecotone

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Abstract

In the grassland/forest ecotone of North America, many areas are experiencing afforestation and subsequent shifts in ecosystem carbon (C) stocks. Ecosystem scientists commonly employ a suite of techniques to examine how such land use changes can impact soil organic matter (SOM) forms and dynamics. This study employs four such techniques to compare SOM in grassland (*Bromus inermis*) and recently forested (~35 year, *Ulmus* spp. and *Quercus* spp.) sites with similar soil types and long-term histories in Kansas, USA. The work examines C and nitrogen (N) parameters in labile and recalcitrant SOM fractions isolated via size and density fractionation, acid hydrolysis, and long-term incubations. Size fractionation highlighted differences between grassland and forested areas. N concentration of forested soils' 63–212 μm fraction was higher than corresponding grassland soils' values (3.0 ± 0.3 vs. 2.3 ± 0.3 mg $g_{fraction}^{-1}$, $P < 0.05$), and N concentration of grassland soils' 212–2000 μm fraction was higher than forested soils (3.0 ± 0.4 vs. 2.3 ± 0.2 mg $g_{fraction}^{-1}$, $P < 0.05$). Similar trends were observed for these same fractions for C concentration; forested soils exhibited 1.3 times the C concentration in the 63–212 μm fraction compared to this fraction in grassland soils. Fractions separated via density separation and acid hydrolysis exhibited no differences in [C], [N], $\delta^{15}N$, or $\delta^{13}C$ when compared across land use types. Plant litterfall from forested sites possessed significantly greater N concentrations than that from grassland sites (12.41 ± 0.10 vs. 11.62 ± 0.19 mg g_{litter}^{-1}). Long-term incubations revealed no differences in C or N dynamics between grassland and forested soils. $\delta^{13}C$ and $\delta^{15}N$ values of the smallest size and the heavier density fractions, likely representing older and more recalcitrant SOM, were enriched compared to younger and more labile SOM fractions; $\delta^{15}N$ of forested soils' 212–2000 μm fraction were higher than corresponding grassland soils (1.7 ± 0.3‰ vs. 0.5 ± 0.4‰). $\delta^{13}C$ values of acid hydrolysis fractions likely reflect preferential losses of ^{13}C-depleted compounds during hydrolysis. Though C and N data from size fractions were most effective at exhibiting differences between grassland and forested soils, no technique conclusively indicates consistent changes in SOM dynamics with forest growth on these soils. The study also highlights some of the challenges associated with describing SOM parameters, particularly $\delta^{13}C$, in SOM fractions isolated by acid hydrolysis.
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1. Introduction

Rising levels of atmospheric CO_2 (Schimel, 1995) and nitrogen (N) deposition (Galloway et al., 1995) challenge scientists to understand how ecosystems will respond to these perturbations. A significant part of that challenge is to comprehend how carbon (C) and N in labile and more refractory soil organic matter (SOM) fractions are processed in both grassland and forested ecosystems. It is through the development of stable SOM that these

ecosystems can sequester C for long periods of time (up to tens of thousands of years) (Lynch, 1991; Schlesinger and Lichter, 2001) and can retain ecosystem N (Aber et al., 1998; Kaye et al., 2002).

Intact forest ecosystems can harbor significant quantities of C in stable SOM (McColl and Gressel, 1995; Schlesinger, 1997). However, recent studies indicate that mineral soil C can be slow to accumulate in regions experiencing reforestation or afforestation. Studies in pine ecosystems in southeastern North America indicate that while aboveground gains in C accumulation can be impressive, incorporation of that C in the belowground component can be relatively small (Richter et al., 1999; Schlesinger and

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Lichter, 2001), even after decades of development. Jackson et al. (2002) show that afforestation (i.e. woody plant development in grasslands) results in soil C accretion only in relatively dry areas, and that wetter regions may not experience these gains in soil C. These studies challenge our conception of forest development generating significant mineral soil C gains, and generate an interesting controversy when compared with works that suggest belowground accumulation of C in mineral soil and the O horizon can increase significantly with reforestation (Johnson, 1992; Bouwman and Leemans, 1995; Archer et al., 2001).

Numerous investigators have also examined SOM accumulation in grassland ecosystems (Anderson, 1977; Gebhart et al., 1994; Burke et al., 1995), generating additional results that challenge our understanding of factors that govern SOM formation. As with forests, intact grasslands can harbor large quantities of SOM (Schlesinger, 1997), but even after significant time periods, restored grasslands do not exhibit SOM contents similar to those of intact systems (Kindscher and Tieszen, 1998). Grassland soils can exhibit relatively fast formation of stable SOM under laboratory conditions, however (Kaye et al., 2002).

Because the features governing the formation of stable SOM in both forests and grasslands are unclear, these issues have received recent attention in the scientific literature (Haile-Mariam et al., 2000; Loya et al., 2003; Williams et al., 2004). These investigators have employed a suite of methods to examine soils' content and, in some cases, the formation rate of stable SOM; some employ stable isotopic signatures of the C and N in SOM as indicators of SOM dynamics and/or stability. To assess variables related to the most stable fraction of SOM, soil samples must be divided into different functional fractions (Schlesinger, 1997). These groups can be classified as labile, relatively recalcitrant, and stable OM, reflecting the degree to which they are susceptible to microbial attack and subsequent degradation.

There are numerous techniques for isolating SOM fractions. Traditional soil chemistry techniques commonly call for chemical fractionation to assess the composition of various SOM compounds, but these approaches have been viewed as crude estimators of biologically relevant fractions (Killham, 1994). Size fractionation can be an effective way of separating soils into components that represent SOM with varying recalcitrance (Tiessen and Stewart, 1983). Investigators also have examined soil C and N dynamics using density fractionation (Spycher et al., 1983; Boone, 1994; Compton and Boone, 2002). Papers that specifically respond to the current interest in soil C sequestration have employed chemical means of separation (acid hydrolysis, Loya et al., 2003) as well as size fractionation (Schlesinger and Lichter, 2001), or a combination of size and density techniques (Haile-Mariam et al., 2000). Work addressing the fate of N deposition has employed soil incubations to separate stable and labile

SOM fractions (Kaye et al., 2002). All of these methods have varying definitions of the most biologically stable SOM fraction: the smallest fraction (size fractionation); the heavier fraction (density fractionation); the non-hydrolyzable fraction (acid hydrolysis); or the non-mineralized organic material during long-term (several months) incubations. Though these fractions have significant meaning within the context of these studies, comparing organic C and N concentrations or isotopic signatures across studies is challenging because of the different methods employed.

This study explores grassland and forest SOM and these methodological issues by (1) analyzing SOM properties in similar soils supporting grassland and forest stands; and (2) comparing different methods of assessing SOM fractions that are commonly employed by ecosystem scientists. I assessed SOM C and N properties in grassland and forest soils that have similar origins and, until forest development began ~35 years ago on half of the sites, have experienced the same land use history. I employed four methods commonly used by ecosystem scientists to isolate relatively labile and recalcitrant SOM fractions: size, chemical, and density fractionations, and long-term incubations. I examined fractions resulting from size, chemical, and density techniques for their C and N concentrations and isotopic signatures. I compared these results with C and N dynamics as determined in long-term incubations. The work attempts to elucidate how land cover (i.e. grassland vs. forest) can affect regional C and N dynamics via SOM formation and storage; the study also attempts to elucidate how these methods differ in their capacity to isolate SOM fractions of varying age and susceptibility to microbial attack.

2. Materials and methods

2.1. Site description and soil and litterfall sampling

Soils were collected in March 2004 at the University of Kansas Field Station and Ecological Reserves (KSR) in northeastern Kansas ($39°$ N, $94°$ W) (Fitch and Kettle, 1988). The area has a temperate, mid-continental climate characterized by cold winters and hot summers. Mean annual precipitation totals approximately 900 mm, with a 185 day growing season. The area represents the tallgrass prairie/forest ecotone, at the western edge of the eastern deciduous forest biome and the eastern edge of the tallgrass prairie region. Soils are a mosaic of clay loams and silty clay loams derived from shale and limestone or glaciofluvial deposits. Soils are classified as fine, montmorillonitic, mesic Aquic Argiudolls (Pawnee clay loam) and fine, montmorillonitic, mesic Typic Argiudolls (Oska silty clay loam) (USDA Soil Conservation Service, 1977). Soil pH_{water} in the region ranges from 6.0 to 6.7 (Billings, unpublished data).

Eight sites were chosen for this study, representing two land cover types, each at four replicated locations. Mapped boundaries of all sites were established by KSR personnel