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Effects of soil texture on soil carbon and nitrogen dynamics after cessation of agriculture

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Abstract

Soil organic matter (SOM) is an important ecosystem carbon (C) pool that is often depleted by agriculture. SOM content tends to be positively correlated with soil clay concentration among sites, but it is unknown how clay concentration affects the rate of SOM accumulation over time after cessation of agriculture. I used a 40-year chronosequence of 62 former agricultural fields in western Minnesota to determine the influence of clay concentration on the accumulation of soil C pools following agricultural abandonment. As time since cessation of agriculture increased, total soil organic carbon (SOC), unhydrolyzable C, microbial biomass C, labile C calculated from a laboratory soil incubation (C_l), and aggregate size all increased, while potential net nitrogen (N) mineralization and the decay constant of the labile C pool, k_l, decreased. However, clay concentration had no effect on total soil C pool sizes or rate of accumulation. Clay concentration correlated positively with aggregate size and the rate of aggregate accumulation, and it correlated negatively with potential net N mineralization rates regardless of field age. These results indicate that on former agricultural fields converted to perennial grassland, soil texture may not be a significant factor influencing SOM accumulation rates on decadal time scales.

Keywords: Carbon cycle; Clay; Grain size; Land management; Nitrogen; Total organic carbon; Soil dynamics

1. Introduction

Soil organic matter (SOM) is the repository for approximately 60% of the global terrestrial carbon (C) pool and is especially sensitive to agricultural land management (West and Post, 2002). An estimated 55 Pg C were released from the soil to the atmosphere during the 19th and 20th centuries because of agriculture (Paustian et al., 2000). SOM accumulates when perennial vegetation is established on former agricultural fields, creating a potential sink for atmospheric C (Post and Kwon, 2000; Follett, 2001). Yet, the factors that influence the rate, type, and magnitude of this accumulation are still unknown.

Factors that influence the formation of soils over long periods of time–climate, organisms, relief, and parent material–may also affect the accumulation of soil organic carbon (SOC) on decadal timescales in former agricultural fields (Jenny, 1941). Variation in grassland vegetation (the "organisms" factor) has a minimal effect on SOC pools and rates of accumulation in the Great Plains of North America (Vinton and Burke, 1997; McLauchlan et al., 2006). Other research suggests that variation in the parent material state factor, leading to

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differences in soil texture or clay concentration, may explain variation in the rate of SOC accumulation and C sequestration.

There is some evidence that clay concentration may explain variation in rates of SOC accumulation. First, maximum and average SOC content increase with increasing soil clay content across several sites on the Great Plains (Nichols, 1984; Burke et al., 1989). However, this relationship is not global—sometimes SOC is better correlated with factors other than clay such as extractable aluminum, allophane content, or specific surface area (Percival et al., 2000; Krull et al., 2003). Nonetheless, the relationship between clay concentration and SOC content is sufficiently strong that SOM models such as Century (Parton et al., 1987) and RothC (Jenkinson, 1990) assume that SOM decomposition decreases as clay concentration increases, such that if all other factors are equal, SOC accumulates faster as soil clay concentration increases. The prediction that increasing clay concentration increases the rate of accumulation of SOC over decadal timescales has not been directly tested or empirically verified.

Clay content may have distinct effects on the decomposition of different SOC pools (Franzluebbers et al., 1996). For example, respiration from soils during the early stages of a laboratory incubation, when labile SOC was being mineralized, was not influenced by clay (Wang et al., 2003). However, later in the same incubation, when more recalcitrant SOC pools were being mineralized, clay content slowed the rate of mineralization. Some SOM models are beginning to incorporate this heterogeneous clay effect on C decomposition (Muller and Hoper, 2004). In situ C mineralization rates generally decrease with increasing clay content (Hassink, 1997), although laboratory incubations do not always show this trend (Scott et al., 1996). These observations have led to the conclusion that clay particles protect some portion of SOC from decomposition.

The same mechanisms that protect SOC from decomposition in clay-rich soils may cause them to accrue SOC more rapidly than sandy soils. Protection of SOC by clay particles has been postulated to occur through at least two separate mechanisms. First, as SOC becomes humified, it is chemically stabilized and adsorbed onto negatively charged clay minerals with high surface area. Second, SOC is physically protected from microbial mineralization through the formation of soil aggregates. The process of aggregate formation often occurs hierarchically, and the presence of clay particles enables this process (Tisdall and Oades, 1982; Six et al., 2000). Additionally, clay concentration may alter soil moisture, which in turn affects both decomposition of SOC and C inputs to soils via plant productivity.

Evidence for the role of clay content in soil nutrient cycling, especially the key step of nitrogen (N) mineralization, has been mixed. Some studies show that increasing clay content reduces net N mineralization (Cote et al., 2000) but in laboratory conditions, where temperature and moisture differences are controlled, clay content has little effect on net N mineralization rate (Giardina et al., 2001). Regardless of soil texture, net N mineralization decreases with increasing length of time since agriculture as the effects of below-ground disturbance become less pronounced and soil C content increases (Schimel, 1986; McLauchlan et al., 2006).

The primary objective of this study was to determine the effect of soil clay concentration on the rate of change of SOM pools, N cycling, and soil structure over time following cessation of agriculture. To provide a range of soil textures, I studied soils from 62 grassland sites in western Minnesota, USA, that had similar topography, climate, and vegetation but differed in their parent material (either clay-rich glacial till or sandy glacial outwash) and length of time since the cessation of agriculture. I also sampled three native grassland sites that had never been plowed to constrain predictions of ecosystem variables.

I tested three hypotheses relevant to the role of clay in the accumulation of SOM. First, I hypothesized that the accumulation of labile C, as measured by microbial biomass and by respiration from laboratory-incubated soils, would increase with increasing clay concentration because clay promotes the formation of aggregates which protect otherwise labile C from decomposition. Thus, the rate of increase in aggregate size should be positively influenced by clay concentration, as should the rate of increase in labile C pools over time since cessation of agriculture. Second, I hypothesized that the accumulation of recalcitrant C, as measured by unhydrolyzable C, would increase with increasing clay concentration because humified organic molecules, which are resistant to decomposition and have a relatively long turnover time, are chemically stabilized by clay minerals. Third, I hypothesized that soils with high clay concentration would have low rates of potential net N mineralization because organic N is protected from microbial activity either physically or through chemical bonds with clay minerals.

2. Methods

2.1. Study area and soil sampling

To address these hypotheses, I identified a chronosequence of 62 former agricultural fields in Grant and Otter