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Tillage effects on soil carbon fractions in the Sanjiang Plain, Northeast China

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Abstract

Soil organic carbon (SOC) is important for crop production, improving soil quality, and regulating global C cycling. The objective of this study was to estimate C fraction dynamics under the influence of tillage in the Sanjiang Plain of Northeast China. Rate of decline in the free light fraction (FLF) C concentration was much greater than that of intra-aggregate light fraction (ILF) C, heavy fraction (HF) C and SOC during the initial 5 years of cultivation ($p < 0.05$). Cultivation led to accumulation in HF-C compared to the other fractions. The contribution of different fractions to respiration varied with cultivation. In native marshland, HF-C, FLF-C and ILF-C were responsible for 33%, 63% and 4% of the soil respiration, respectively. In soil cultivated for 1 or 3 years, contributions of combined FLF-C and ILF-C to respiration were higher than HF-C. However, after 5 years of cultivation, contributions of HF-C to respiration (55%) were higher than that of combined FLF-C and ILF-C (45%). In soil cultivated for 35 years, the HF-C was responsible for almost 69% of the respiration. Therefore, C dynamics in the soil are controlled by the behavior of LF-C in the natural soil and short-term (<5 years) cultivated soils. In long-term (>5 years) cultivated soils, C dynamics are controlled by the behavior of HF-C.

Keywords: Free light fraction; Intra-aggregate light fraction; Heavy fraction; Soil organic C; Northeast China

1. Introduction

The Sanjiang Plain, one of the largest freshwater marshes in China, has experienced intensive cultivation over the past 50 years. About 3.8 Mha of native marshland has been converted, resulting in significant changes to the hydrological properties of the region (Liu and Ma, 2000). While there are reports documenting changes in methane emissions (Ding et al., 2002, 2003, 2004), the effects of tillage on soil organic carbon (SOC) remain largely unknown.

Soil organic C is viewed as an important factor affecting soil quality and long-term sustainability of agriculture. Decrease in SOC leads to a decline in cation exchange capacity of soils, soil aggregate stability and crop yield (Freixo et al., 2002). Besides being a source and sink of nutrients for plants, SOC plays an important role in the C cycle, as it accounts for the major terrestrial pool of this element (Freixo et al., 2002). Unfortunately, it often takes years before changes in agricultural management lead to detectable changes in the quantity and quality of SOC (Hassink et al., 1997). SOC contains fractions with a rapid turnover rate as well as fractions with a slower turnover rate (Schimel et al., 1985).

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Physical fractionation of SOC is a powerful tool in land use change studies (Christensen, 2000). Density fractionation physically separates soil into low- and high-density fractions, referred to as the light fraction (LF) and heavy fraction (HF). Light fraction primarily consists of mineral-free organic residues at various degrees of decomposition that are, relative to whole soil, enriched in C and N (Christensen, 1992). Heavy fraction is a more stable, high-density organo-mineral fraction with lower C concentration (Golchin et al., 1995). Changes in these different fractions, especially in the low-density fraction, may be more sensitive to management-induced impacts on soil than total SOC (Barruis et al., 1996; Guggenberger and Zech, 1999; Shepherd et al., 2001; Freixo et al., 2002; Swanston et al., 2002; Roscoe and Buurman, 2003). Swanston et al. (2002) incubated seven mineral soils from forests in Washington and Oregon for 300 days, and reported that C mineralization followed the pattern: free light fraction (FLF) > intra-aggregate LF (ILF) > heavy fraction (HF). Heavy fraction was responsible for 35% of the total respiration, while the combined FLF and ILF accounted for the remainder. Whalen et al. (2000) also investigated C and N mineralization from LF and HF additions to soil samples collected from three long-term experimental sites. Few studies, however, have investigated changes in LF dynamics in systems with differing periods of cultivation. Since SOC contains several fractions with different turnover rates, we hypothesized that C dynamics in the soil are controlled by the behavior of the different C fractions with differing periods of cultivation.

The objectives of this study were to estimate the dynamics of soil C fractions, and to investigate whether C dynamics in the soil are controlled by the behavior of the different C fractions with differing periods of cultivation.

2. Material and methods

2.1. Site characteristics and sampling

A site was selected in the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Science, in Sanjiang Plain of China, at approximately 47°35′N, 133°31′E. The average altitude is 55.4–57.9 m. Mean annual temperature is 1.9 °C with an average frost-free period of 125 d. Mean annual precipitation is 550–560 mm, with July and August accounting for more than 65% of the total precipitation. The sites were described in detail by Ding et al. (2004).

We studied adjacent sites within 2 km that were originally dominated by *Deyeuxia angustifolia*. Sites were annually cultivated for 1, 3, 5, 9, 15, and 35 years. All fields were plowed to 15–20 cm by machine using moldboard plow. Soybean (*Glycine max Merr*) was planted continuously each year in May and harvested in September or October. The C-horizon was Quaternary Period sediment. Soils at all sites were classified as Hydric Medihemists, with silty clay texture. Three plots (40 m × 40 m) were arbitrarily established in each field. For each plot, 20 cores (0–10 cm depths) were taken before spring cultivation. Field moist cores were pooled, sieved (<2 mm), and stored at 4 °C.

2.2. Density fractionation

Light fraction was separated by flotation in a NaI solution (1.7 g cm^{-3}) before and after aggregate disruption. In brief, 100 g of sample was placed in a 1 l beaker with 500 ml of NaI solution, gently shaken by hand, and left standing at room temperature for about 1 h. The supernatant was aspirated with a vacuum pump, centrifuged (15 min, 3500 rpm), and filtered through a membrane filter. The fraction recovered on the filter was washed with 100 ml of 0.01 M $CaCl_2$ followed by 200 ml of distilled water iteratively. The sediment in the centrifuge tubes was placed back in the beakers, resuspended in NaI and gently shaken by hand. The same procedure was repeated two times as described above. The three sub-fractions were combined, oven-dried at 50 °C and stored for analysis. This fraction was called free light fraction (FLF). The sediment in the centrifuge tubes and beaker was resuspended and ultrasonicated at 400 J ml^{-1}, with a calibrated Vibracell VCX 600 probe-type model. Centrifugation and filtration were repeated three times as described above and the fraction recovered from the supernatant was referred to as intra-aggregate light fraction (ILF). The sediment in the centrifuge tubes and beaker was the heavy fraction (HF), and the HF was washed once with 0.01 M $CaCl_2$ and about 10 times with distilled water, oven-dried at 50 °C and stored for analysis (Roscoe and Buurman, 2003). The C concentration in total soil and fractions were determined using a FLASH1112 CNS Analyzer.

2.3. Laboratory incubation

Respiration was determined on 20 g (oven-dry basis) whole soil, 5 g (oven-dry) HF mixed with 15 g acid-washed quartz sand (650–850 μm diameter), 1 g (oven-dry) FLF mixed with 19 g acid-washed quartz sand, and 0.5 g (oven-dry) ILF mixed with 19.5 g acid-washed