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Temporal changes in soil carbon and nitrogen storage in a hybrid poplar chronosequence in northern Alberta

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Abstract

Sequestering C in biomass and soils in hybrid poplar plantations can help mitigate global climate change caused by the rising atmospheric CO_2 concentration. However, the impact of the establishment of hybrid poplar plantations on C and N storage and dynamics is poorly understood. We studied the distribution and temporal changes of C and N in soil organic matter (SOM) density fractions in 2-, 5-, 11-, and 13-year-old (age as in 2006) hybrid poplar stands that form a chronosequence by sampling the plantations in both 2004 and 2006. Sodium polytungstate (SPT, density = 1.6 g mL^{-1}) was used to fractionate the soil into light (LF, density < 1.6 g mL^{-1}), occluded light (LFo, density < 1.6 g mL^{-1}) and heavy fractions (HF density > 1.6 g mL^{-1}). The results showed that C and N concentrations (g kg^{-1} of fraction) in the SOM density fractions decreased in the order of LFo > LF > HF, while the C/N ratio was in the order of LF > LFo > HF. The amount of C and N stored in the LF, LFo and HF fractions and bulk soil in the top 10 cm of soil was: 149-504, 70-336, 1380-2876 and 1617-3776 g m^{-2}, respectively, for C, and 6-26, 3-20, 149-271 and 152-299 g m^{-2}, respectively, for N. From 2004 to 2006, C and N storage decreased in the LF and LFo fractions but increased in the HF fraction in the youngest stand. However, stand-age effects were likely muted by high inherent soil variability among the stands. Carbon storage in the light fraction was responsive in the short term to hybrid poplar plantation establishment.
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Keywords: Carbon sequestration; Hybrid poplars; Light fraction; Boreal Forests; Dissolved organic matter

1. Introduction

Sequestering C in biomass and soils is widely believed to be an effective method to mitigate global climate change caused by the rising atmospheric carbon dioxide concentration. Carbon sequestration resulting from incremental forest management, afforestation and reforestation are eligible for receiving C credits under the Kyoto protocol (UNFCC, 1998). Afforestation/reforestation projects have the potential to remove a significant amount of CO_2 from the atmosphere in the short and medium term, and can be deployed relatively rapidly and at a moderate cost (FAO, 2004). In fact the quantities of C sequestered may meet a significant portion of the Kyoto commitments for some countries in Europe and North America, regions with vast and fast-growing plantation forests (FAO, 2004). There is also a growing interest, especially by forest companies in North America, to plant fast-growing hardwood species (such as hybrid poplars) to sustainably supply the fiber needed by the pulp and paper industries. These fast growing plantations can also add an appreciable amount of C to the soil. Hansen (1991), for example, reported that soils in hybrid poplar plantations in north central United States sequestered 24.4 Mg C ha^{-1} more soil C than adjacent soils under agricultural row crops after an average of 15 years.

In order to verify the C credits in the context of the Kyoto Protocol, dynamics and storage of organic matter in such systems need to be better understood, particularly in terms of how C and N storage in the soil changes with stand development, because of the high intensity of cultivation during initial years of plantation establishment. While quantifying C storage in above-ground components is a relatively easy task, quantifying

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C sequestration in soils usually presents greater challenges (Garcia-Oliva and Masera, 2004). In particular, what constitutes the functional pools of soil organic matter (SOM) and the response of those pools to management practices remains poorly understood (Six et al., 2000a), especially in the context of hybrid poplar plantations. Changes in management practices may cause soil C stocks to increase or decrease depending on the interactions with previous land-use, climate and soil properties (IPPC, 2006). Cultivation generally decreases the total SOM and changes the size distribution and stability of aggregates and SOM properties (Six et al., 2000a,b; John et al., 2005). However, due to high natural soil variability, it is often difficult to detect short or even medium term land-use and/or management induced changes in total SOM at sampling intensities that are often used (Smith, 2004).

Soil organic matter is composed of a series of fractions (pools) that have different rates of biochemical and microbial degradation, and management practices can influence the distribution of organic C and N among the SOM pools (Cambardella and Elliott, 1994; Golchin et al., 1994). Physical, chemical, and biological methods are often employed to separate SOM fractions with different turn-over rates (Dubeux et al., 2006). Of those methods, physical fractionation of SOM by density and the subsequent determination of their C content have been widely employed to characterize SOM properties and dynamics (Cambardella and Elliott, 1993, 1994; Golchin et al., 1994; Swanston et al., 2002; Dubeux et al., 2006). This method is considered less disruptive than the chemical methods and can separate fractions of SOM that are more sensitive to cultivation than total C (Cambardella and Elliott, 1994; Six et al., 2000b). The fractions so identified are also acclaimed to represent meaningful functional pools that relate to essential soil processes such as SOM mineralization and aggregate formation (Janzen et al., 1992; Christensen, 2001).

The commonly used SOM fractions (operationally defined) are the light fraction (LF), representing poorly decomposed and relatively labile SOM, and the heavy fraction (HF) corresponding to more recalcitrant SOM associated with mineral soil (Golchin et al., 1994; Swanston et al., 2002). Further separation of LF into 'free' and 'occluded' (within aggregate) pools could also be made after applying some dispersive force (e.g. ultrasonic) to separate the partially decomposed litter material trapped within aggregates (Golchin et al., 1994). The occluded light fraction (LFo) has undergone more decomposition while it was physically protected within aggregates and is less decomposable than the free LF. Due to its labile nature, the free LF can be quickly depleted upon cultivation and hence its dynamics maybe an important early indicator of management induced change and may be used for predicting long term changes in SOM.

Another labile component of SOM with ecological significance is the dissolved organic matter (DOM) or dissolved organic C (DOC). Albeit a minor fraction of SOM, DOM is much more sensitive to soil management than SOM and may be used as an indicator of soil natural functions (Silveira, 2005). According to studies reviewed in McDowell (2003), DOM ranges in age from hours to hundred of years and it varies widely in chemical composition and degradability (Silveira, 2005). An important ecological role DOM plays in some environments is providing C substrate for methanogenesis (hence methane production) and as an electron donor for denitrification and oxidation-reduction reaction, a process that produces nitrous oxides (Zsolnay, 2003). The ecological significance of dissolved organic N (DON) is less known. Some studies indicate that DON might be a refractory product resulting from microbial degradation of SOM (McDowell, 2003). Generally, the mechanism for and controls of DOC and DON degradation in soil (McDowell, 2003) and, particularly, how land-use change and forest management practices affect the amount and dynamics of DOC and DON are not well understood (Chantigny, 2003).

The objective of this study was to investigate changes in C and N storage in different SOM fractions, including as DOM, in a chronosequence of hybrid poplar (HP) stands. We hypothesized that the light fraction and DOM would decrease rapidly during the initial years of plantation establishment but would increase gradually as the stands grow older, while the heavy fraction would increase gradually with stand age.

2. Materials and methods

2.1. Site description and sampling procedures

The soil samples used in this study were collected from hybrid polar plantation stands near the Alberta-Pacific Forest Industries Inc. (Al-Pac) mill site. The Al-Pac mill site (54°49′ N and 113°31′ W, 626 m ASL) is located about 200 km north of Edmonton. A detailed description of the 2-, 5-, 11- and 13-year-old stands (age as in 2006) selected for study is provided in Saurette et al. (2006). Briefly, mean annual temperature of the site is 2.1 °C and mean annual precipitation is 503.4 mm, of which one-third falls as snow. The dominant soil type in the area is Luvisolic soils. The selected stands had high natural variability in organic C and N contents (Saurette et al., 2006).

Soil samples were collected in August 2004 and September 2006 from the top 0-10 cm mineral soil in each of the 2-, 5-, 11- and 13-year-old hybrid poplar (*Populus deltoides* × *Populus petrowskyana* var. Walker) plantation stands. Samples were only collected in August 2004 and September 2006 as those dates represent the starting and ending points for this experiment, and so to allow us to evaluate the change in C storage in density fractions over time. Each of the 2- and 5-year-old stands had three replications, while the 11- and 13-year-old stands had only one replication because only those stands were available for those age classes. Planting of hybrid poplars at industrial scale is only a recent event in Alberta. Few chronosequences studied and reported in the literature are replicated. All stands in this study are located within an approximately 6 km radius. There were no differentiated L, F or H horizons in any of the studied stands. This was attributed to site maintenance activities (disking and mowing) of the plantations which is done for the first 3 to 4 years, and to a very small amount of litter fall input especially in the young stands, and a relatively fast rate of litter decomposition (Saurette et al., 2006).

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