Soil Biology & Biochemistry 40 (2008) 1901–1907

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Timber harvesting alters soil carbon mineralization and microbial community structure in coniferous forests

A. Chatterjee [a], G.F. Vance [b,*], E. Pendall [c], P.D. Stahl [b]

[a] Carbon Management and Sequestration Center, Ohio State University, Columbus, OH 43210, USA
[b] Department of Renewable Resources, University of Wyoming, Laramie, WY 82070, USA
[c] Department of Botany, University of Wyoming, Laramie, WY 82070, USA

ARTICLE INFO

Article history:
Received 11 December 2007
Received in revised form 27 March 2008
Accepted 31 March 2008
Available online 12 May 2008

Keywords:
Lodgepole Pine
Ponderosa Pine
Soil organic C pools
Phospholipid fatty acids

ABSTRACT

Timber harvesting influences both above and belowground ecosystem nutrient dynamics. Impact of timber harvesting on soil organic matter (SOM) mineralization and microbial community structure was evaluated in two coniferous forest species, ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*). Management of ponderosa pine forests, particularly even-aged stand practices, increased the loss of CO_2-C and hence reduced SOM storage potential. Changes in soil microbial community structure were more pronounced in ponderosa pine uneven-aged and heavy harvest stands and in lodgepole pine even-aged stand as compared to their respective unmanaged stands. Harvesting of trees had a negative impact on SOM mineralization and soil microbial community structure in both coniferous forests, potentially reducing coniferous forest C storage potential.

1. Introduction

Maximizing belowground carbon (C) storage in forest ecosystems through sustained management practices requires an understanding of the relationship between management practices and soil biogeochemical processes. Forest management can result in either positive or negative impact on the quantity and quality of soil organic residues, rates of C and nitrogen (N) mineralization, as well as soil microbial community structure (Grayston and Renneberg, 2006). Alteration in these ecosystem components and functions through forest management practices can impact C dynamics. Carbon storage at the ecosystem level depends on the balance between photosynthesis C inputs and losses in the form of soil respiration (Janzen, 2006). Timber harvesting reduces C inputs and increases C loss due to increased soil respiration. With time, regeneration of young tree stands increases forest productivity as vegetation photosynthesis becomes greater. However, with the inception of harvesting, changes in inputs of organic residues will impact the soil environment, potentially altering soil microbial community structure and, hence, soil biogeochemical processes (e.g., nitrification) connected with microbial phylogeny (Balser and Firestone, 2005). Heterotrophic soil microorganisms mediate the decomposition of plant residues and mineralization of C that play a significant role in C within terrestrial ecosystems (Zak et al., 2003).

An association between soil organic C (SOC) mineralization and microbial community structure has been identified in historically altered forests (Fraterrigo et al., 2006). Change in microbial biomass due to harvesting depends on the magnitude of the disturbance and subsequent soil environmental conditions. Despite continued efforts to understand the impact of harvesting on microbial biomass, results are varied with microbial biomass decreasing (Fraterrigo et al., 2006), increasing (Entry et al., 1986) or remaining constant (Li et al., 2004). Ponder and Tadros (2002) reported that after a forest disturbance particular groups of soil microorganisms became more prevalent. The effect of forest harvesting on soil microorganisms also depends on climate and forest type. Grayston and Renneberg (2006) found forest thinning reduced soil microbial biomass and activity in European beech forests on a cool moist site; however, there was increased soil microbial biomass on a warm dry site of the same forest type. The decomposer community of coniferous forest soils has also been reported to be resistant to initial environmental changes induced by forest harvesting (Siira-Pietikäinen et al., 2001b). Phospholipid fatty acids (PLFAs) are major structural components of cell membranes, excellent indicators of microbial community structure in soil and changes in PLFAs may reflect past and present soil disturbances (Zelles, 1999; Ponder and Tadros, 2002; Mummey et al., 2002).

During forest management, changes in microbial community structure and activity can lead to an alteration or reduction in soil organic matter (SOM) pools by the modification of quantity and quality of available substrates, as well as rate of substrate degradation. Long-term laboratory incubation studies are useful for

* *Corresponding author.* Tel.: +1 307 742 6662; fax: +1 307 766 6403.
E-mail address: gfv@uwyo.edu (G.F. Vance).

0038-0717/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2008.03.018

fractionating SOC into meaningful C pools and can also be used to determine the degree of substrate availability due to different protection mechanisms (Paul et al., 2006). In an Arizona ponderosa pine ecosystem, Grady and Hart (2006) observed that microbial respiration within the surface soil (0–15 cm) of an unmanaged stand was higher than sites that were either burned or thinned and burned. The relationship between microbial community structure and SOC utilization can be used to describe ecosystem responses to forest management practices (Balser and Firestone, 2005).

Timber harvesting has the potential to alter soil physical conditions by changing the soil bulk density, which is dependent on original soil properties, forest type, and soil parent material (Williamson and Neilsen, 2000). Increasing soil bulk density restricts root growth and decreases water and air movement into and through the soil profile that, in turn, influences microbial community structure.

Mechanistic understanding of relationships among soil microbial community structure, soil bulk density and soil C pool utilization is required to predict future C storage potentials under different forest land management scenarios. Soil organic C pools, soil bulk density and microbial community structure were evaluated under different intensities of timber harvesting within ponderosa and lodgepole pine forests in Wyoming, USA. We used this data to assess the impact of timber harvesting on the relationship between soil microbial community structure and soil C mineralization linked with C dynamics in coniferous forest stands. Finlay et al. (1997) concluded that microbial diversity has no discrete role in ecosystem function and it is never depleted to such extent to impair the biogeochemical cycling; however, many soil ecologists do not agree with this contentious finding. Therefore, we hypothesize that timber harvesting had no effect on the processes and microbial community structure associated with forest soil C dynamics with our null hypothesis suggesting there is an effect.

2. Materials and methods

2.1. Experimental field site and sampling design

Study sites were selected in a ponderosa pine [*Pinus ponderosa* (Dougl. ex Laws)] forest located on Wyoming State Forest land near Black Hills National Forest (44°N, 104°W) in northeastern Wyoming and a lodgepole pine [*Pinus contorta* ssp. *latifolia* (Engelm. ex Wats) Critchfield] forest located in the Medicine Bow National Forest (41°N, 106°W) in southeastern Wyoming. In 2004, four ponderosa pine forest stands (unmanaged, even-aged, uneven-aged, and heavy harvest) and two lodgepole pine forest stands (unmanaged and even-aged) were selected for this research study.

Ponderosa pine sites were located on Citadel loam (Fine, smectitic, frigid Glossic Hapludalfs) soils derived dominantly from calcareous sandstone, limestone, and shale. An unmanaged ponderosa pine stand was used as a reference site (NRCS, 2008). It was characterized by high tree density with some rock outcrops and gravelly loam soils. An even-aged ponderosa pine site resulted from a stand replacing wildland fire in 1960. Regeneration of ponderosa pine occurred within the burn area. As a result of pre-commercial thinning and pruning in 1995, the average mature tree age (old cohort) was 46 years. An uneven-aged site located near the even-aged site and adjacent to the burned area was selectively harvested to remove saw timber in 1979 and 1992. A pre-commercial thinning was also undertaken on this site in 1995. The heavy harvest had a several marketable trees harvested in 1985 and 1989. Canopy gaps and abundant understory vegetation characterized the heavy harvest site.

Lodgepole pine sites were located on Erickson (Fine-loamy, mixed, superactive Typic Haplocryalfs) soils derived from quaternary glacial till (NRCS, 2008). Site selected for this study included an unmanaged lodgepole pine stand (135-year old trees) and an even-aged stand (45-year old trees regenerated after the site had been clear-cut). Detailed site descriptions of both sites are presented in Table 1. Soil physicochemical properties of the 0–5 and 5–15 cm soils from both forest types under different management treatments are listed in Table 2.

Within each ponderosa and lodgepole pine treatment, three 50 × 50 m plots were established. Each plot contained three 50 m transects, which were 25 m apart from one another. Three points along each transect (summit, middle and end) were selected for soil sampling. A large number of sampling locations (27 per treatment) were included in this study in order to evaluate soil biogeochemical processes and microbial community structure and to assess within stand variations.

2.2. Soil properties and biogeochemical processes

For soil bulk density (BD) measurements, soil samples were collected from 0–5 and 5–15 cm soil depths using a hammer driven double cylinder core sampler. Thirty soil samples were collected from each treatment stand (i.e., 2 depths × 5 replications × 3 plots). Values (g cm^{-3}) for BD were obtained using the gravimetric method outlined by Blake and Hartge (1986).

Fifty-four soil samples for each treatment were analyzed for SOC (i.e., 2 depths × 9 replications × 3 plots). The SOC percent concentration was determined indirectly by subtracting inorganic C content from total soil C content. Total soil C and N percent concentration were determined by dry combustion (Nelson and Sommers, 1996) using an Elementar Vario-Macro CN analyzer (Elementar Analysensysteme, GmbH, Germany) and inorganic C percent concentration was measured by the pressure calcimeter method (Sherrod et al., 2002). The SOC pool of a particular soil depth was calculated using percent SOC concentration and soil BD value.

The magnitude of different C pools (active, slow, and resistant) and C mineralization rates were estimated using a three pool constrained model described by Paul et al. (2001):

Table 1
Forest types, locations, treatment methods, and management details of the ponderosa and lodgepole pine study sites

Forest type	Location	Treatments	Details
Ponderosa pine *Pinus ponderosa* [Dougl. ex Laws]	Near Black Hills National Forest, New castle, WY (44°N, 104°W)	Unmanaged	100-Year old stand.
		Even-aged	46-Year old stand. Regeneration after stand replacement fire in 1960. Pre-commercial thinning and pruning in 1995. Firewood sale in 1997.
		Uneven-aged	110-Year old stand. Commercial timber harvested in 1979 and 1992. Prescribed burning occurred in 1980. Pre-commercial thinning was done in 1995. Firewood sale took place in 1995.
		Heavy harvest	90-Year old stand. All marketable trees were harvested in 1985 and 1989. Pre-commercial thinning and pruning done in 1992. Firewood sale occurred in 1993.
Lodgepole pine *Pinus contorta* ssp. *latifolia*	Medicine Bow National Forest, Laramie, WY (41°N, 106°W)	Unmanaged	No management practices occurred, 135-year old stand.
		Even-aged	Regeneration after site was clear-cut, 45-year old stand.