Forest Ecology and Management 326 (2014) 163–170

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of harvest residue management on soil carbon and nitrogen processes in a Chinese fir plantation

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ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form 16 April 2014
Accepted 17 April 2014
Available online 17 May 2014

Keywords:
Cunninghamia lanceolata
Labile carbon pools
Soil carbon
Soil CO_2 efflux
Subtropical China

ABSTRACT

Plantation management can affect ecosystem soil carbon (C) and nitrogen (N) cycles. However, how different harvest residue management strategies impact soil C and N processes over the long term is largely unclear. In this study, we examined effects of harvest residue management on soil C and N concentrations, labile soil C and N pools and soil CO_2 efflux (*Rs*) at different stages after Chinese fir (*Cunninghamia lanceolata*) was replanted in subtropical China. The residue management treatments were slash and burning, whole-tree harvesting, stem-only harvesting and stem only harvesting with double residue retention. Our results showed that the harvest residue management treatments did not differ significantly in their effect on soil C and N, mineral N (NH_4^+-N plus NO_3^--N), dissolved organic C or total dissolved N concentrations, except for soil N concentrations in surface soil (0–10 cm) at year 3 and soil total dissolved N concentrations at year 12, which were significantly lower where the slash was burnt than in the double residue retention treatment. Similarly, *Rs* did not differ significantly among the four residue management strategies at year 15. Topsoil temperature and topsoil moisture were also unaffected by harvest residue management treatment. Soil temperature was found to be the most important factor controlling the temporal pattern of *Rs*, accounting for 65.8% of seasonal variation of *Rs*. There was no significant difference in temperature sensitivity of *Rs* (Q_{10}) or annual *Rs* among the four treatments. These results indicated that harvest residue management may not significantly cause long-term effects on soil C cycling and N availability in subtropical Chinese fir plantations.

1. Introduction

The global area of forest plantations reached 187 million hectares (ha) in 2005, with an expansion rate of almost 5 million ha per year (Lee et al., 2005). Forest soils are well recognized for their importance in global carbon (C) cycling and play a key role in sustaining forest productivity and environmental quality (Johnson and Curtis, 2001; Lal, 2005). Under proper management, forest soils can act as net sinks of atmospheric C, sustain commercial biomass production, and provide other environmental services (Lal, 2005; Vanguelova et al., 2010; Huang et al., 2011). In second-rotation forest plantations, residues from tree harvests are important components of litter which is the primary source of soil organic matter (SOM). Harvest residue management practices affect soil C and nitrogen (N) storage by changing the quantity or quality of organic matter inputs to soil, causing physical disturbance to the soil (which may influence soil temperature and moisture content) and changing soil nutrient levels (O'Connell et al., 2004; Powers et al., 2005; Jandl et al., 2007). Thus, appropriate harvest residue management is crucial for the long term sustainability of plantations (Mendham et al., 2003; Chen and Xu, 2005).

Studies of changes in soil C and N under various harvest residue management treatments have given divergent results (Mendham et al., 2003; Powers et al., 2005; Jandl et al., 2007; Huang et al., 2011), so the impacts of plantation management practices on soil C and N continue to receive attention. For instance, in a review of harvest impacts on C storage, Nave et al. (2010) suggested that Alfisols and Spodosols exhibited no significant changes in soil C

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http://dx.doi.org/10.1016/j.foreco.2014.04.023
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in response to harvesting, but Inceptisols and Ultisols lost soil C (13% and 7%, respectively). This difference may be related to varying soil texture (e.g. clay content), which is a key factor controlling soil C retention (Scott et al., 1999). Jandl et al. (2007) emphasized the necessity of distinguishing between labile and stable pools of soil C when considering the effects of residue management. Some studies showed that soil C increased with residue retention (Smaill et al., 2008; Huang et al., 2011), while others suggested that the effects of harvest residue on soil C would diminish with time (Mendham et al., 2002; Jandl et al., 2007). Soil CO_2 efflux (*Rs*) is the main pathway for C to move from terrestrial pools to the atmosphere. Sayer et al. (2011) found that litter addition would significantly increase *Rs* in tropical forests and this effect was sustained over several years. Recently, most reports have focused on the short-term (<10 years) effects of harvest residue management on *Rs* (Chen and Xu, 2005; Butnor et al., 2006; Versini et al., 2013), but the long-term effects are still poorly understood. Soil properties, the chemical quality of SOM and time since harvest need to be considered together in order to completely determine the harvest impacts on soil C and N processes in managed forests.

The subtropical area in South China is considered an important region for high biodiversity and a great natural reserve for endemic plant species (Wu, 1980). Subtropical evergreen broadleaved forest is the climax vegetation in this region. In recent decades, large tracts of natural evergreen broadleaved forests in many regions of South China have been transformed into secondary forest, plantations, orchards and arable land (Sheng et al., 2010). Chinese fir (*Cunninghamia lanceolata*) is one of the most important plantation tree species in South China in terms of commercial value and planting area. At present, it covers 12 million ha and accounts for about 6.5% of all forest plantations in the world (Chen et al., 2013). In accordance with the Intergovernmental Panel on Climate Change (IPCC, 2007), China has committed to increase its total area of forest by 40 million ha in the next decade (Xu, 2011) and plantations of Chinese fir will likely increase rapidly in this region. Many previous studies have indicated that transformation of broadleaved forests to pure Chinese fir plantations would decrease the soil C pool and production of the first rotation (Yang et al., 2005; Sheng et al., 2010; Chen et al., 2013). While there are few studies of the long-term effects of harvest residue management on soil C and N pools and C emissions after planting the second Chinese fir rotation. Long-term studies in Chinese fir plantations are essential to improve our understanding of forest management practices on soil C and N and on the processes influencing soil C and N.

Here, we conducted a field experiment to examine the effects of harvest residue management on soil C and N concentrations, labile soil C and N pools and soil CO_2 efflux after a second rotation of Chinese fir was planted in subtropical China. The objectives of this study were to test the following hypotheses: (1) increased harvest residue retention would increase soil C and N at an early stage (<10 years) of the rotation, (2) effects of different harvest methods on soil C and N would become weaker after 10 years, and (3) harvest residue retention would not increase *Rs* after 15 years because of the lack of impact on SOM from harvest residue retention.

2. Material and methods

2.1. Site description

The experimental site is located at the Xiayang forest farm (26°48′N, 117°58′E), northwest Fujian Province, South Eastern China. The research site was described in Huang et al. (2013). The experimental forest (5 ha in total) was established in October 1996 on hill slopes (230–278 m elevation). The site had a deep red soil classified as a clay loam Acrisol according to the FAO/UNESCO classification. The soil was acidic and developed on deeply weathered deposits of Cretaceous Period granite and conglomerate (Yang et al., 2005). The soil profile was well-developed and characterized by a B horizon of clay accumulation, which was reddish or yellowish brown in color due to the accumulation of iron oxides (Zhu et al., 1983). The climate is humid subtropical monsoon with a short and mild winter in January and February, and a long, hot and humid summer between June and October. Spring and autumn are warm transitional periods. Mean annual precipitation and temperature (1971–2000) were 1653 mm and 19.5 °C, respectively, with most rain events occurring in spring and summer (Fan et al., 2006).

2.2. Experimental design

A first-rotation Chinese fir plantation was clear-felled by chainsaws in December 1996 at an age of 29 years. After harvesting, it was estimated that approximately 26.1 and 9.9 Mg ha^{-1} of harvest residue and forest floor from the previous rotation were retained on site, respectively. Then four harvest residue management treatments were randomly applied in a block, each block being replicated four times. The four harvest residue management treatments were: (1) slash burning – stems were harvested and all surface organic matter (including all harvest residue, slashed understory vegetation and forest floor) was burned on site, (2) whole tree harvest – all harvest residues were removed without disrupting the forest floor, (3) stem only harvest – commercial-sized boles were removed leaving branches and foliage on the site, and (4) double residue – residue from whole tree harvest treatment plots was moved to plots where stems only had been removed. Each plot had an area of 20 m × 30 m. The plots were planted with Chinese fir seedlings in February 1997 at 2 m × 2 m spacing to make up 150 trees per plot (2500 stems ha^{-1}). The plots, separated by a buffer of two rows of trees, were fertilized at planting with 38, 55, and 20 kg ha^{-1} of N, phosphorus and potassium, respectively.

2.3. Soil sampling, C and N concentrations

Within each plot, a total of 12 soil cores (2.5 cm in diameter) were randomly collected along a diagonal transect from 0–10, 10–20 and 20–40 cm soil depths at 3, 6, 9, 12, and 15 years after tree planting. Forest floor materials (needle litter and partially decomposed materials) were carefully removed before the soil cores were collected. Soil samples were transported to the laboratory and stored at 4 °C for two days prior to processing. Soil samples were sieved (2 mm sieve) to remove large pieces of organic debris prior to analysis. The C and N concentrations in finely ground (<0.2 mm) soil sub-samples were determined using a LECO EPS-2000 CNS thermal combustion furnace (LECO Corp., St Jose, MI).

2.4. Labile soil C and N pools

Soil mineral N (including NH_4^+-N and NO_3^--N) was extracted using 2 M KCl solution (soil: extractant ratio of 1:5) and measured using a Lachat Quickchem automated ion analyzer (Quik Chem method 10-107-064-D for NH_4^+ and 10107-04-1-H for NO_3^-).

Water extractable soil dissolved organic C (DOC) and total dissolved N (TDN) concentrations of soil samples in 0–10 and 10–20 cm layers collected between years 9 and 15 were determined. Briefly, moist soil samples (4 g oven-dry equivalent) were incubated with 40 ml distilled water at 24 °C in 50 ml polypropylene centrifuge tubes on a reciprocating shaker for 1 h (200 rev min^{-1}). The mixture in the tubes was then centrifuged