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Research article

Effects of forest regeneration practices on the flux of soil CO_2 after clear-cutting in subtropical China

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ABSTRACT

Reforestation after clear-cutting is used to facilitate rapid establishment of new stands. However, reforestation may cause additional soil disturbance by affecting soil temperature and moisture, thus potentially influencing soil respiration. Our aim was to compare the effects of different reforestation methods on soil CO_2 flux after clear-cutting in a Chinese fir plantation in subtropical China: uncut (UC), clear-cut followed by coppicing regeneration without soil preparation (CC), clear-cut followed by coppicing regeneration and reforestation with soil preparation, tending in pits and replanting (CCR_P), and clear-cut followed by coppicing regeneration and reforestation with overall soil preparation, tending and replanting (CCR_O). Clear-cutting significantly increased the mean soil temperature and decreased the mean soil moisture. Compared to UC, CO_2 fluxes were 19.19, 37.49 and 55.93 mg m^{-2} h^{-1} higher in CC, CCR_P and CCR_O, respectively ($P < 0.05$). Differences in CO_2 fluxes were mainly attributed to changes in soil temperature, litter mass and the mixing of organic matter with mineral soil. The results suggest that, when compared to coppicing regeneration, reforestation practices result in additional CO_2 released, and that regarding the CO_2 emissions, soil preparation and tending in pits is a better choice than overall soil preparation and tending.

1. Introduction

Forest soils store more than 70% of global soil organic carbon and play significant roles in the reduction or increase of atmospheric CO_2 concentrations (Jobbágy and Jackson, 2000; Six et al., 2002). Soil respiration is estimated to release 50–75 Pg C yr^{-1}, making it the major flux in the global carbon cycle (Raich and Schlesinger, 1992). Soil CO_2 flux, resulting from autotrophic root respiration and microbial respiration, is strongly influenced by soil temperature, soil moisture and root mass (Yashiro et al., 2008). As the atmospheric concentration of CO_2 continues to increase (Pérez et al., 2013), we need more knowledge on CO_2 flux from forest soils.

Whether forest ecosystems are C sources or sinks depends on forest type, tree age and forestry practices (Jandl et al., 2007). Forestry practices may disturb soil and affect soil carbon stocks and flux (Laporte et al., 2003). In plantations that are periodically harvested for timber, a variety of reforestation practices can be applied to ensure the establishment of new stands. However, how these practices affect soil CO_2 flux is not clear. To mitigate climate change, forestry practices that maintain or increase forest soil C should be chosen.

Clear-cutting is commonly used in plantation forestry (Rosenvald and Lohmus, 2008; Ma et al., 2013). The decomposition of leaves, twigs, branches, stumps, and roots left on the clear-cut site may compensate the decreases in root and rhizosphere respiration (Pumpanen et al., 2004; Jandl et al., 2007). Due to changes in soil temperature (Davidson et al., 1998; Striegl and Wickland, 1998; Laporte et al., 2003; Kim, 2008), air temperature (Lavoie et al., 2013), soil moisture (Carlyle and Than, 1988; Laporte et al., 2003; Lavoie et al., 2013), soil water table depth (Zerva and Mencuccini, 2005), root activity (Bowden et al., 1993; Pangle and Seiler, 2002),

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decomposition rate of soil organic matter (Binkley, 1986), and soil pH (Kim, 2008), clear-cutting affects soil CO_2 flux. Clear-cutting has been reported to increase (Ewel et al., 1987a; Gordon et al., 1987; Londo et al., 1999; Laporte et al., 2003; Kim, 2008; Aguilos et al., 2014), to decrease (Edwards and Ross-Todd, 1983; Weber, 1990; Zerva and Mencuccini, 2005), to initially decrease and then increase (Gao et al., 2015), and to have no effect on soil CO_2 flux (Fernandez et al., 1993; Toland and Zak, 1994; Mallik and Hu, 1997; Yashiro et al., 2008). The contradictory results may be attributed to differences in clear-cutting practices, vegetation (Laporte et al., 2003) and environmental factors (Jandl et al., 2007).

After clear-cutting, reforestation is commonly used to establish a new stand. Soil preparation, brush clearing, weeding, herbicide application, digging, fertilization, prescribed burning and planting seedlings are applied in various combinations to facilitate the growth and survival of new seedlings (Jandl et al., 2007). Compared with coppicing regeneration, reforestation practices cause additional soil disturbance. Reforestation may affect soil temperature and moisture, and influence soil respiration. The mixing of organic matter with soil in mounding may accelerate soil organic matter decomposition and increase soil respiration (Mallik and Hu, 1997; Giasson et al., 2006). However, mounding leads to a significant decrease in CO_2 flux because vegetation is mostly removed (Levy-Booth et al., 2016). Drainage can stimulate aerobic decomposers and increase CO_2 flux (Jaatinen et al., 2008; Mojeremane et al., 2012). Fertilization may increase soil respiration by stimulating decomposer community (Jassal et al., 2010) or fine root growth (Cleveland and Townsend, 2006), but fertilization may also cause a net reduction in CO_2 emissions (Mojeremane et al., 2012). Due to the various combinations of reforestation practices, estimating the effect of reforestation on CO_2 flux is complicated.

Chinese fir (*Cunninghamia lanceolata*) forests cover almost eleven million hectares in subtropical China, approximately 7% of forest area in China (SFAPRC, 2014). Chinese fir forests also represent a key component of China's forest carbon sink because of their large area and fast growth (Zhang et al., 2004; Wang et al., 2009). The rotation period in Chinese fir plantations is usually approximately 26 years (Yu, 1996). Clear-cutting is the predominant harvesting method, followed by either coppicing regeneration alone or combined with replanting. Replanting commonly involves soil preparation, brush clearing and digging holes prior to planting seedlings. Pure Chinese fir or mixed Chinese fir and broadleaved forests are established using coppicing regeneration alone, coppicing regeneration combined with soil preparation in pits, or overall soil preparation with replanting. Understanding how these methods affect soil C flux is critical for promoting sustainable forestry.

The purpose of this study was to determine how coppicing regeneration and two types of reforestation methods in Chinese fir plantations affect soil CO_2 flux and the environmental controls of CO_2 flux.

2. Materials and methods

2.1. Site description

The experiment was conducted from April 2014 to December 2015 in the township of Qingshan (30°14′54″N, 119°50′35″E), Lin'an County, Zhejiang Province, China. The study area has subtropical monsoon climate with mean annual temperature of 16.4 °C and a precipitation of 1629 mm (Wu et al., 2015). During the study period the mean annual temperature in 2014 was 18.7 °C, ranging from 6.1 °C in December to 27.8 °C in August (Fig. 1). The average monthly precipitation was 149.7 mm, ranging from 6 mm in December 2014 to 382.5 mm in June 2015 (Fig. 1). The frost-free period lasted 239 days. The soil is classified as a Ferrosol according to the FAO soil classification scheme and mostly derived from granite. Average altitude of the experimental site is 150 m.

The Chinese fir forests in this study originated from reforestation in 1989 after a clear-cut. In 2014 the stand had 1350 stems ha^{-1} with a mean diameter at breast height of 16.5 cm, a mean height of 13.8 m, and a canopy closure of 88%. The shrub layer was dominated by *Mallotus apelta*, *Lindera glauca*, and *Eurya rubiginosa*. The grass layer was dominated by *Paederia scandens*, *Gynostemma pentaphyllum*, and *Pteris multifida*. At the beginning of the experiment soil pH (H_2O) at 0–5 cm depth was 5.7 ± 0.2 in the uncut blocks and 5.6 ± 0.3 in the clear-cut blocks.

2.2. Experimental design

In recent decades, the successive plantation of pure Chinese fir has been widely applied in southern China. However, many studies have reported that this approach led to dramatic decreases in soil

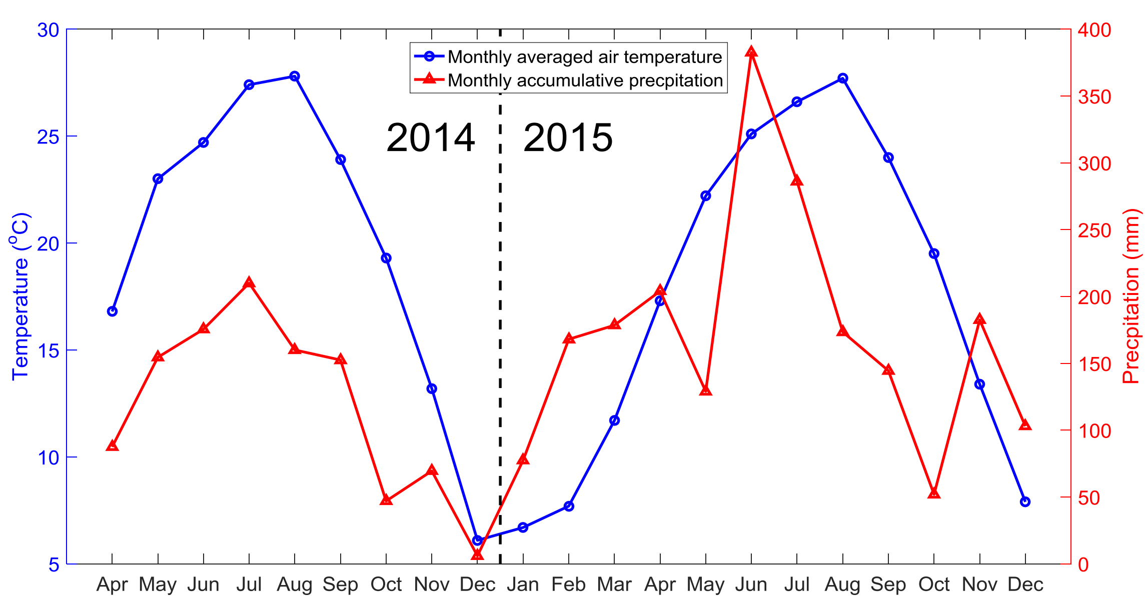

Fig. 1. Mean average air temperature and monthly accumulative precipitation during the experimental period.