Science of the Total Environment 444 (2013) 363–368

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

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

Soil CO_2 flux dynamics in the two main plantation forest types in subtropical China

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HIGHLIGHTS

- ► We investigate soil CO_2 flux in Chinese fir and Moso bamboo plantations.
- ► Soil CO_2 flux in both forest types shows similar daily and seasonal dynamic patterns.
- ► CO_2 flux in Chinese fir forest is more sensitive to temperature than Moso bamboo.
- ► Higher CO_2 flux was observed in the Moso bamboo than in the Chinese fir forest.
- ► This may influence the carbon sequestration capacity of these two forest types.

ARTICLE INFO

Article history:
Received 11 September 2012
Received in revised form 1 December 2012
Accepted 3 December 2012
Available online 29 December 2012

Keywords:
Chinese fir
Moso bamboo
Plantation
Soil CO_2 fluxes
Soil respiration
Subtropical

ABSTRACT

Chinese Fir and Moso bamboo are the two most important forest plantation species in subtropical China. However, information on greenhouse gas emissions from these forests is still scarce. A field study was carried out to compare soil CO_2 flux dynamics in Chinese Fir and Moso bamboo forests over a 12-month period using the LI-8100 Soil CO_2 Flux System. The soil CO_2 flux in both forest types showed similar daily and seasonal dynamic patterns with the highest soil CO_2 efflux at 14:00–16:00 in summer and the lowest in winter. Moso bamboo forest showed significant higher ($P<0.01$) annual mean soil CO_2 fluxes (52.9 t CO_2 ha^{-1} yr^{-1}) than Chinese fir forest (27.9 t CO_2 ha^{-1} yr^{-1}). The large difference in soil CO_2 fluxes may potentially influence the carbon cycle of the two forest types at the ecosystem scale. The CO_2 flux from the soil showed a significant positive correlation ($P<0.0001$) with soil temperature at 5 cm depth, a significant negative correlation ($P<0.01$) with air relative humidity, and no significant correlation with soil moisture in either forest types. The Q_{10} value of soil respiration was higher in Chinese fir than Moso bamboo forest, indicating that soil respiration under Chinese fir forest will be more sensitive to temperature change. This study contributes to better understanding of the role Moso bamboo and Chinese fir forests may play in carbon cycle and global warming mitigation.

1. Introduction

Globally, the pool of carbon in soils is greater than the pool contained in vegetation or the atmosphere, and changes in soil carbon content can therefore greatly affect the global carbon budget (Raich and Schelsinger, 1992; Bellamy et al., 2005). Soil respiration is a major flux in the global carbon cycle, second only to gross primary productivity (Box, 1978; Raich and Schelsinger, 1992). Therefore, even a small change in the soil respiration flux may have considerable implications for the rate of change in atmospheric CO_2 and therefore for climate change.

The effect of increased atmospheric CO_2 and associated global warming on forest soil carbon stocks is complex involving both positive and negative feedbacks. Firstly, plant photosynthesis accelerates under elevated atmospheric CO_2 conditions, leading to increased accumulation of soil carbon (DeLucia et al., 1999; Lichter et al., 2008), but also increases the rate of soil respiration partially cancelling this effect (Jackson et al., 2009). Secondly, because increases in temperature accelerate soil respiration it is feared that global warming may increase the release of soil organic carbon (SOC) to the atmosphere (Cox et al., 2000). However, the impacts of climate warming on soil decomposition dynamics have not been fully resolved and it is unclear whether locally derived respiration/temperature relationships can be used to predict

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http://dx.doi.org/10.1016/j.scitotenv.2012.12.006

the effects of climate warming on soil respiration (Giardina and Ryan, 2000; Davidson and Janssens, 2006).

The role that forests will play in mitigation of climate change through carbon sequestration will also be greatly influenced by forest management practices, and by global levels of deforestation and reforestation. Historically, deforestation has contributed significantly to the increase in atmospheric CO_2. During deforestation, not only is there a release of carbon associated with the loss of forest biomass, but there can also be a longer term decline in SOC. This is because forest soils often contain higher stocks of organic carbon than soils of other land uses (Lal, 2005). There is less information on the effect on SOC of clearance of natural forest followed by conversion to managed plantation forest, although harvesting of temperate zone forests is associated with a loss of soil carbon especially from the forest floor layer which can take decades to recover under the regrowing forest (Nave et al., 2010). There are some evidence that soil carbon declines following conversion of natural to plantation forest in subtropical China. Implementation of intensive management practices, such as weeding, cultivation and mulching, can enhance soil respiration rates in forest plantations (Jiang et al., 2009; Liu et al., 2011; Zhang et al., in press). Zhou et al. (2006) found the SOC in a Moso bamboo (*Phyllostachys pubescens*) plantation declined by 34.7% 20 years after establishment before approaching a stable equilibrium status, while Wang et al. (2005) reported a 26.4% decline in SOC between a first and second generation Chinese fir (*Cunninghamia lanceolata*) plantation.

The aim of this study was to determine soil respiration rates in subtropical Chinese plantation forests to improve our understanding of how these forests may contribute to climate change mitigation through carbon sequestration. In subtropical China, Chinese fir forest and Moso bamboo forest are the two most representative types of subtropical plantation forests established after clear cutting the evergreen broadleaf forest, a regional climax community. Chinese fir is a fast growing species prized for its wood quality, and has been widely planted for timber production in southern China (Yu, 2006), with plantations covering approximately 9.11 million ha and accounting for 30% of all plantations in China (Lei, 2005). Moso bamboo forests are the most important source of non-wood forest products in China and cover 3.37 million ha, accounting for 70% of China's bamboo forest area and 80% of the world's Moso bamboo area (Song et al., 2011).

The most noticeable characteristic of these two types of plantation is their rapid growth rates. The annual carbon fixation of the tree crop at age 12 years was 5.10 $t \cdot ha^{-1}$ in a Moso bamboo forest and 5.41 $t \cdot ha^{-1}$ in a Chinese fir forest, these rates being higher than typical sequestration rates in tropical mountain rain forest (Zhao et al., 2009; Zhou and Jiang, 2004). This high annual rate of carbon accumulation makes plantations of Moso bamboo and Chinese fir become the most efficient forms among subtropical forest vegetation for carbon fixation, and they thus show considerable potential for mitigating climate change through carbon sequestration. Both types of forest have received increasing attention in recent decades and are regarded as important components in a government strategy of using forest plantations in southern China to address climate change (Song et al., 2011; Zhao et al., 2009).

Most previous studies of carbon dynamics in Moso bamboo and Chinese fir forests have focused on stand productivity, storage and distribution of carbon (Xiao et al., 2007; Chen et al., 2009; Zhao et al., 2009). However, there has been no direct comparison and comprehensive assessment of the soil CO_2 fluxes in these two main plantation types. Because soil respiration is a key part of the carbon cycle in forest ecosystems, this limits our understanding of the true role that forest plantations in southern China may play in mitigating climate change. The objectives of this study were to compare the dynamics of soil CO_2 fluxes between the two major types of forest plantation in subtropical China, and to identify the environmental factors affecting them.

2. Materials and methods

2.1. Study site

The study site was located in the Tianmu Mountain (30°18′30″N to 30°21′37″N and 119°24′11″E to 119°27′11″E) situated within the northwestern region of Zhejiang Province with a maximum elevation of 1506 m. The climate is representative of a subtropical monsoon region with a mean annual precipitation of 1420 mm and a mean annual temperature of 16.8 °C. Effective accumulated temperature greater than 10 °C is 2700° days, with July (24 °C mean temperature) and January (3 °C mean temperature) as the warmest and coldest months, respectively. Average annual sunshine hours are approximately 1940 h with an average of 234 frost-free days per year. Monthly mean air temperature and precipitation during the study period are shown in Fig. 1. The soil type is yellow red soil (Chinese system of soil classification), which is equivalent to Hapludult in USDA Soil Taxonomy (Soil Survey Staff of USDA, 1999). The soil is slightly acidic with a pH ranging from 4.7 to 6.0 (Wu et al., 2008).

Both the Chinese fir and Moso bamboo plantations were established from native evergreen broadleaf forest about 60 years previously in sites of similar topography and soil type. The main management activity is harvesting by thinning in both plantations. In the Chinese fir plantation, trees are selectively harvested at an intensity of approximately 20% at about 15-year intervals. The Moso bamboo forest is harvested by thinning mature stems at age 6 or 7 years. In addition, a proportion of the bamboo shoots are selectively harvested each year. The Chinese fir forest contains trees with a greater range of ages while the bamboo forest contains plants within the age range 1–6 years. There has been no fertilizer application or weeding in either plantation. There are a few understorey species in both forests, principally *Linderag lauca*, *Acer palmatum* and *Trachelospermum jasminoides* in the Moso bamboo forest and *Acer davidii*, *Nandina damestica*, *Camellia sinensis* and *Carex tristachya* in Chinese fir forest.

2.2. Experimental design and measurement

In May 2007, three 20 m × 20 m measurement plots were established within each plantation. The culm height and external culm diameters at 1.3-m height above ground level or diameter at breast height (DBH) in each plot were measured. Soil samples were collected from 0 to 20 cm depth using stainless cutting ring samplers with 10 cm inner diameter from seven randomly selected locations in each plot and combined to form a composite sample. Soil bulk density was measured with cutting ring sampler method. The samples were brought back to the lab for further analysis. Soil total organic C content was determined using a potassium dichromate method. Soil total N concentration was measured using a semi-micro Kjeldhal method. Soil pH was determined using a pH meter on a 1:2 (*w*:*v*) soil/water extract. All methods described above for soil analysis are from Lu (1999). Stand and soil characteristics of both stands are summarized in Table 1.

Within each plot, four randomly placed soil CO_2 flux sampling PVC collars (10 cm inside diameter, inserted 5 cm from the ground surface into the soil) were installed. All PVC collars remained permanently installed throughout the experiment. Green plants growing inside each collar were cut carefully close to the soil surface with scissors before sampling. The soil CO_2 flux was measured using the LI-8100 soil CO_2 flux system (LI-COR Inc., Lincoln, NE, USA). Soil temperature and volumetric water content at 5 cm depth were measured adjacent to each respiration collar with two portable probes provided with the LI-8100. Other environmental factors, including air pressure, air relative humidity and air CO_2 density, were also recorded automatically during experiment by the LI-8100. Measurements were carried out at 2-hour intervals between 8:00 and 18:00 on selected sunny days in May,