Agricultural and Forest Meteorology 220 (2016) 1–9

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Effect of thinning-induced gap size on soil CO_2 efflux in a reforested spruce forest in the eastern Tibetan Plateau

Xueyong Pang[a,b,*], Bin Hu[a,b], Weikai Bao[a,b,*], Thiago de Oliveira Vargas[c], Guanglong Tian[d,e]

[a] Key Laboratory of Mountain Ecological Restoration and Bioresource Utilization of Chinese Academy of Sciences, Chengdu Institute of Biology, Chinese Academy of Sciences, PO Box 416, Chengdu 610041, China
[b] Ecological Restoration and Biodiversity Conservation Key Laboratory of Sichuan Province, PO Box 416, Chengdu 610041, China
[c] Department of Environmental Studies, University of California at Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA
[d] Environmental Monitoring and Research Division, Monitoring and Research Department, Metropolitan Water Reclamation District of Greater Chicago, Lue-Hing R&D Complex, 6001 W. Pershing Road, Cicero, IL 60804, USA
[e] Department of Civil, Architectural & Environmental Engineering, Illinois Institute of Technology, 3201 S. Dearborn Street, Chicago, IL 60616, USA

ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form
24 December 2015
Accepted 6 January 2016

Keywords:
Soil respiration
Thinning
Forest gap size
Root biomass
Understory
Spruce plantation

ABSTRACT

Understanding the effects of forest management practices (e.g. thinning) on soil respiration (R_s) is crucial for the accurate estimation of forest carbon budget. However, little is known about the response of R_s to forest thinning in the subalpine region and its linkage to changes in environmental factors induced by thinning. We aimed to quantify the response of R_s rate to various gap sizes following thinning treatments, and to explore the relationships between R_s and soil temperature and moisture and other biophysical factors in the different gap sizes. We applied the thinning by simulating gap formation (four gap sizes at 0, 74, 109 and 196 m^2) in a 26-year old spruce plantation in the eastern Tibetan Plateau. We measured R_s monthly before (July to November 2008) and after (December 2008 to June 2012) thinning, as well as monthly soil temperature and moisture and other biophysical factors. Thinning tended to decrease fine root biomass, litterfall, soil extractable C, and increased soil temperature and soil moisture. The change in soil temperature and moisture depended on the time after thinning and the size of forest gap. We found that R_s showed an immediate decrease in initial stage after thinning, followed by a gradual increase with understory development towards the level at the control plot. Overall, thinning decreased R_s rate by 14.9%, 15.8% and 25.8% in the small, intermediate and large gap, respectively, as compared to the control. We concluded that the decrease in R_s rates by thinning in a spruce plantation was driven by the decline in tree root biomass and reduction in soil labile C. The positive effect of soil temperature elevation under thinning on R_s was masked by other factors, and the development of understory vegetation after thinning gradually offset the thinning-induced R_s reduction. Our results suggest the need to consider a set of abiotic and biotic factors induced by forest thinning intensity on R_s rates in modeling the response of soil C cycling to forest management practices.

1. Introduction

Soil CO_2 efflux or respiration (R_s) is the second largest flow in the global carbon (C) cycle, accounting for 30–80% of total ecosystem respiration in forests (Schlesinger and Andrews, 2000). In the terrestrial ecosystem, R_s rate is profoundly influenced by both biotic and abiotic factors (Buchmann, 2000). Changes in biophysical factors such as soil temperature, soil moisture, vegetation properties, microbial activity, and soil organic carbon (SOC) content can cause changes in R_s rate (Gaumont-Guay et al., 2008; Ryan and Law, 2005).

Forest management practices, such as thinning, pruning, harvesting, fertilization, and prescribed fire, can lead to changes in R_s through influencing soil temperature, soil moisture, nutrient availability, and vegetation productivity. Thinning by simulating gap formation in the forest development has been suggested as an approach for promoting late-successional forest characteristics and maintaining native biodiversity in managed forests (Arbuckle, 2010; Bolton and D'Amato, 2011; Pang et al., 2013; Wang et al.,

* Corresponding authors at: Chengdu Institute of Biology, Chinese Academy of Sciences, PO Box 416, No.9, Section 4, Renmin Nan Road, Chengdu 610041, China. Tel.: +86 28 82890528; fax: +86 28 82890288.
E-mail addresses: pangxy@cib.ac.cn (X. Pang), baowk@cib.ac.cn (W. Bao).

http://dx.doi.org/10.1016/j.agrformet.2016.01.004

2010). Thinning may affect R_s rate by influencing root biomass (Brumme, 1995; Peng and Thomas, 2006; Tang et al., 2005b), soil microclimate (Galhidy et al., 2006; Gray et al., 2002; Pang et al., 2013), belowground C allocation (Selig et al., 2008; Tian et al., 2010; Zu et al., 2009), and microbial community structure (Arunachalam and Arunachalam, 2000; Zhang and Zak, 1998; Zu et al., 2009). Thinning may cause the immediate decrease in R_s rate due to the decrease in respiration from tree roots (Tang et al., 2005b). Simultaneously, micro-environmental improvement, such as light, nutrient availability, soil temperature, and soil moisture may lead to the increase in heterotrophic respiration.

The response of R_s rate to thinning may also depend on the intensity of thinning (Marthews et al., 2008) as the change in biotic and abiotic factors may differ under different gap sizes. In a large gap (high intensity thinning), as water uptake by roots of surrounding trees is negligible, soil drying is controlled by the evaporation from soil surface at the initial stage of thinning, and the transpiration of understory plants and evaporation from soil surface after the development of understory vegetation. Soil temperature is related to the heating of direct solar radiation and cooling due to evaporation. In contrast, in a small gap (low thinning intensity), soil drying is controlled by water uptake by roots from surrounding trees, although soil temperature is still related to direct solar radiation with some cooling due to evaporation. In an unthinned forest, soil drying is controlled by water uptake of tree roots and soil temperature by heat conduction from deep soil layers with some evaporation and sensible heat transfer. These differences in soil water movement and heating due to gap sizes could result in variations in R_s rate across different thinning intensities (Tang et al., 2005b). Although thinning is a common forest management practice in the eastern Tibetan Plateau, how the response of R_s rate to thinning varies with the intensity of thinning (or gap size) and the time after thinning is still unknown.

We hypothesized that (1) R_s rate decreased immediately after thinning due to the reduced tree root respiration as a result of forest crown removal, but gradually recovered to the level in the unthinned forest due to the improvement in soil temperature and moisture and rapid development of understory vegetation, and (2) the response of R_s rate to thinning was dependent on the intensity of thinning, which drove the changes in biophysical factors. Therefore, our main objectives in this study were to examine how R_s rate varied with gap size and time after thinning in a spruce plantation in the eastern Tibetan Plateau, and what biophysical factors induced by thinning drove the change in R_s rate.

2. Material and methods

2.1. Study site description

This study was conducted at Maoxian Mountain Ecosystem Research Station of Chinese Academy of Sciences in Sichuan, China (31°37′N and 103°54′E). It has a montane temperate climate with the mean annual precipitation of 900 mm falling mainly from May to September (Fig. 1). The mean annual temperature is 8.9 °C with the mean maximum monthly temperature of 18.8 °C in July and the mean minimum monthly temperature of −1.1 °C in January (Jiang et al., 2011). This region is colloquially described as "high mountain, deep valley" and is located in a transition zone from the Sichuan Plains to the Tibetan Plateau, China (Chen et al., 2010).Various landforms and microclimates support a rich biodiversity and abundant forest resources. The vegetation in this region is subalpine forests with Minjiang Fir (*Abies faxoniana*) and spruce (*Picea asperata*) as the typical and dominant tree species (Chen et al., 2010). The primary subalpine forests in the region were felled at a large scale during the period of 1940s to 2000s

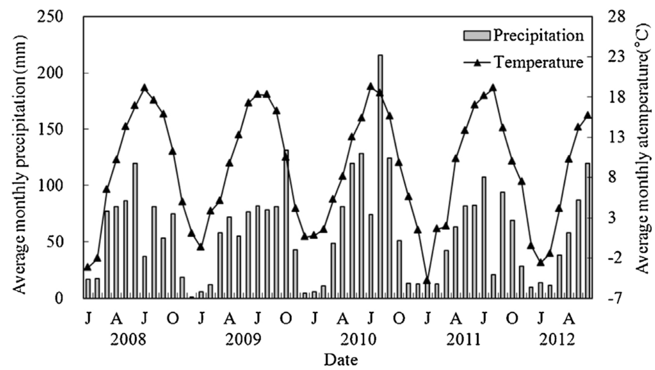

Fig. 1. Monthly precipitation and average air temperature from January 2007 to June 2012 at the study site.

(Pang et al., 2011). The reforestation was performed in these cutting areas, and such plantations comprised of approximate 60% of forest areas with 7.3×10^5 ha in western Sichuan, China. Due to the initial purpose of timber requirement, most plantations were designed with monoculture tree species (Pang and Bao, 2011). Spruce is one of the typical cultivated tree species in the subalpine region of the eastern Tibetan Plateau.

The spruce plantations in our study site were established mostly in 1985 (Jiang et al., 2011). The collection of litter, equivalent to 16.8–20.2 g C m^{-2} yr^{-1} in the fall and wild mushrooms and Chinese medicinal plants in the spring occurred each year. No management was given to the plantation. In 2008, the mean diameter at breast height (DBH) of the trees was 19.1 cm with a mean height of 10.0 m. The tree density was 1450 stems ha^{-1} for individuals with DBH > 3 cm. The canopy leaf area index (LAI) was approximately 3.5, and the tree canopy coverage was 81% at the end of the 2008 growing season (Table 1). The major understory shrubs and herbs are *Phlomis umbrosa*, *Asparagus filicinus*, *Thladiantha davidii*, *Plantago major*, *Sinosenecio oldhamianus*, *Carpesium divaricatum*, *Prenanthes henryi*, *Rosa sericea*, *Thalictrum uncinulatum* (Jiang et al., 2011; Zhao et al., 2015). The soil at the experimental site was characterized as an Udic Luvisols (IUSS Working Group WRB, 2007). The detailed soil analyses in plots for the study were presented in Table 1.

2.2. Thinning treatment

Previous research indicated that high density and monoculture spruce plantation reduced soil fertility, forest productivity and ecological functions in the subalpine area of the eastern Tibetan Plateau, China (Bao et al., 2007). In 2008, a thinning technique by simulating natural gap formation, i.e. selectively cutting groups of trees within a small area to create a forest gap, was applied to improve soil fertility and forest productivity in a 5 ha spruce plantation (Wang et al., 2010; Jiang et al., 2011). There were four thinning treatments, i.e. large gap (approximately 196 m^2), intermediate gap (approximately 109 m^2), small gap (approximately 74 m^2), and control (no thinning, CK). Gap size was calculated based the area of a polygon surrounded by gap-edge trees. The four individual plots were replicated three times in a randomized complete block design. In July 2008, the experimental plots were delimited and fenced. The height, DBH and canopy area of each tree were measured and the understory species composition and cover were recorded. In November 2008, thinning was conducted for the chosen gaps. In thinning plots we removed stems, branches, and leaves of the cut trees, but retained stumps of 50 cm above the ground. The understory shrub and herbaceous species were left in the plots.