Journal of Arid Environments 75 (2011) 51–57

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Temporal and spatial variation in soil respiration of poplar plantations at different developmental stages in Xinjiang, China

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ARTICLE INFO

Article history:
Received 6 February 2010
Received in revised form
31 August 2010
Accepted 7 September 2010
Available online 26 September 2010

Keywords:
Fine root biomass
Forest plantation
Soil carbon efflux
Stand age

ABSTRACT

Soil respiration is essential for the understanding of carbon sequestration of forest plantations. Soil respiration of poplar plantations at three developmental stages was investigated in 2007 and 2008. The results showed that mean soil respiration rate was 5.74, 5.10 and 4.71 μmol CO_2 m^{-2} s^{-1} for stands of 2-, 7- and 12-year-old, respectively, during the growing season. Soil temperature decreased with increasing plantation age and canopy cover. As plantation matured, fine root biomass also declined. Multiple regression analysis suggested that soil temperature in the upper layer could explain 73–77% of the variation in soil respiration and fine root biomass in the upper layer could explain further 5–8%. The seasonal dynamics of soil respiration was mainly controlled by soil temperature rhythm and fine root growth since soil water availability remained adequate due to monthly irrigation. Spatial variability of soil respiration varied considerably among three age classes, with the coefficient of variation of 28.8%, 22.4% and 19.6% for stands of 2-, 7- and 12-year-old, respectively. The results highlight the importance of the development stage in soil carbon budget over a rotation, since both temporal and spatial variation in soil respiration displayed significant differences at different developmental stages.

1. Introduction

Worldwide concern with global warming and its effects on our environment require a better understanding of the processes contributing to this global change. One of the key questions need to be addressed is the dynamics of the large amount of global carbon (Fang and Moncrieff, 2001). Soil respiration is the second largest carbon flux in terrestrial ecosystems, and plays a critical role in global carbon cycling. It is estimated that approximately 70% of ecosystem respiration in temperate forests is from soil (Lal, 2005); globally, soil respiration reaches to 50–75 Pg C y^{-1} (Raich and Schlesinger, 1992), 10 times greater than the annual CO_2 emission from fossil fuel combustion (Schlesinger and Andrews, 2000). Thus, soil respiration undoubtedly exerts a great effect on atmospheric CO_2 concentration, and consequently on global warming. Furthermore, a potential positive feedback between increasing temperature and enhanced soil respiration that may ultimately accelerate global warming has been widely accepted (Grace and Rayment, 1999; Schlesinger and Andrews, 2000).

According to FAO (2000), forest plantations covered 187 million ha worldwide. In the next decades, the rates of reforestation and afforestation across the world are likely to increase as many countries seek to compensate for the carbon emission through forest plantations (Gladstone and Ledig, 1990; Houghton, 1996) in order to meet the requirement of Kyoto Protocol. Moreover, soil carbon sequestration by managed forest has been considered as a "truly win–win strategy" and the most promising choice to offset the accumulation of CO_2 in the atmosphere (Lal, 2005). Therefore, plantations would have a significant impact as a global C sink (Montagnini and Porras, 1998).

In China, mainly due to the increasing reforestation and afforestation, the forest biomass carbon storage showed a significant increase, from 4.38 Pg C by the end of 1970s to 4.75 Pg C by 1998 (Fang and Chen, 2001). Since the introduction in the 1970s, poplars have been widely incorporated into many managed ecosystems throughout the north China. Up to now, China has the largest poplar plantation area and biomass storage across the world (Fang et al., 2007), which roughly covered an area of 7 million ha in 2007. In

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doi:10.1016/j.jaridenv.2010.09.005

the future, this figure will be expected to increase greatly since the Chinese government intends to develop plantations in the wastelands in northwest China. Concerns about greenhouse gas levels have encouraged research into poplar plantation as a potential C sink, due to its rapid above and belowground biomass accumulation (Dewar and Cannell, 1992; Eissenstat et al., 2000). Ceulemans and Isebrands (1996) reported that poplar hybrids had very fast initial growth rate caused by its higher photosynthetic capacity observed among woody plants. Therefore, *Populus* species have received more and more attention in climate change impact studies (Gielen and Ceulemans, 2001). However, our collective knowledge and research to date have primarily focused on aboveground biomass and physiological responses to environmental factors and less is known about the belowground carbon cycle of hybrid poplars. Specifically, only limited studies have dealt with soil respiration and soil carbon pool in poplar plantations (Coleman et al., 2000; Heilman et al., 1994; Joshi et al., 1997; Pregitzer and Friend, 1996).

Soil temperature and soil moisture are recognized as the main factors controlling the temporal variability of soil respiration (Davidson et al., 1998; Raich and Schlesinger, 1992; Rayment and Jarvis, 2000), and in arid or semiarid lands, soil moisture tends to be a limiting factor of soil respiration due to soil water shortage. Also, in the previous studies, spatial variability of soil respiration in forest ecosystems has been related to changes in root biomass (Hanson et al., 1993), carbon content (LaScala et al., 2000), litter biomass (Fang et al., 1998) and so on. Furthermore, as forests develop from young to mature developmental stages, a number of structural and physiological changes are likely to affect soil respiration (Tedeschi et al., 2006). For instance, the quantity and quality of the aboveground and belowground detritus, root activity can change with the stand age (Jandl et al., 2007; Johnson and Curtis, 2001). So, as a fast-growing species, the poplar plantation is likely to have varying soil carbon dynamics throughout a short-rotation. Therefore, it is necessary to obtain sufficient information on this field to accurately evaluate its soil carbon budget over a full rotation. Based on the measurements of soil respiration, root biomass, soil properties in poplar plantations with different stand ages, the present work is intended to (1) quantify and compare the variations in soil respiration at three development stages of a rotation; (2) describe the temporal and spatial variations in soil respiration; and (3) determine the main factors driving the variation in soil respiration.

2. Materials and methods

2.1. Study site

The study area was located at Pingyuan Forestry Farm, Yili river valley, Xinjiang Province, northwestern China (81°09′E, 43°45′N). The region has a continental semiarid climate with a mean annual precipitation of 203.8 mm. The mean annual temperature ranges from 6.7 to 9.9 °C, with the average temperature of −12.2 °C in January and 22.7 °C in July. The frost-free period lasts on average 162 days, from May to September. Annual sunshine hour reaches to 2800 h. Climate normals for the study site are based on 30 years of meteorological data collected at Yili weather station. The study site is relatively flat with slopes <3° and the mean elevation is 660 m. The soil type is the Sierozems originating from parent material of loess. Soil texture is typical sandy loam with organic matter content of about 1.2–2.5%, total N of 0.1–0.2%, and a pH value of 8–8.5.

Pingyuan Forestry Farm is an experiment center for afforestation using poplar species and its hybrid clones in northwest China, roughly covering an area of 345 ha. Most of the poplar plantations are established on former arable land, which presents a unique opportunity to study the influences of afforestation within the same soil type. Since the introduction in the 1980s, 566 poplar clones had been widely incorporated into many managed ecosystems of Pingyuan Farm. Through the experiments over 20 years, 46 poplar clones are selected for future reforestation and afforestation based on the growth rate, wood production and easy adaptability. In the Pingyuan Forestry Farm, most of the poplar plantations have undergone intensive managements, such as irrigation, fertilization, weed control and so on. As a fast-growing species, the poplar plantation usually has a rotation cycle varying from 7 to 12 years in local managements. Water resources in the farm area are abundant originating from the Yili river, which gives an advantage to plantation development.

Due to plough management and annual weed control, poplar plantation stands are characterized by an almost total absence of understory or sparse herbaceous vegetation such as *Carex liparocarpos, Bromus japonicus* and *Achnatherum splendens*.

2.2. Experimental design

The poplar forest stands were typically established on 3 × 4 m spacing in this study, averaging approximately 833 trees ha^{-1}. The poplar plantations in the study sites were established on former agricultural land. The poplar clone *Populus balsamifera* L. was selected for this research because it was among the main clones for afforestation in Pingyuan Farm. Three stand age classes of plantation were chosen for this study, representative of different developmental stages: 2-year-old stands, just after planting; 7-year-old stands, when canopy was closed, and 12-year-old stands, close to the end of the rotation cycle. Stand age was referred to May 2007, when our measurements were started. In order to minimize the sources of error, we chose age class stands on sites with same parent material, landscape position and prior land use history. All stands had undergone the similar management practices such as fertilization, irrigation and ploughing since their establishments. The stand characteristics of three stand age classes are given in Table 1. In order to minimize the sources of error, replicated ($n = 3$) poplar stands of each age class were chosen based on the same soil type and slope. Three 25 × 30 m fixed plots were randomly set up in each replicate stand and 6–8 subsamples (soil collars) were randomly distributed in each plot, with three of them situated at the base of a tree and the others at halfway between two planting rows. Sample trees were selected within the borders of each stand to minimize any edge effects.

Because the high productivity of poplar plantations depends heavily on water availability, and natural precipitation in the study area cannot meet the water demand of poplar plantations, irrigation is necessary for plantation development. During the growth season (from May to September) in 2007 and 2008, all plots were irrigated monthly, with a rough water amount of 40–45 mm. All measurements were usually taken 3 days later after irrigation.

2.3. Measurement of soil respiration and environmental factors

Soil respiration (SR) was measured with a Li-6400 portable CO_2 infrared gas analyzer (IRGA) equipped with a Li-6400-09 chamber

Table 1
Stand characteristics of poplar plantations at different age (July, 2007).

Parameters	Three age classes		
	2-year-old	7-year-old	12-year-old
Canopy coverage (%)	65	93	98
Mean tree height (m)	8.27 ± 0.8	18.52 ± 0.6	19.31 ± 0.8
Mean diameter at breast height (cm)	9.04 ± 1.1	17.48 ± 1.4	20.88 ± 1.7
Stand density (stem ha^{-1})	833	833	833
Coarse root biomass (t ha^{-1})	0.75 ± 0.3	1.32 ± 0.4	4.34 ± 0.8
pH	8.30 ± 0.02	8.34 ± 0.01	8.35 ± 0.01

Data are mean ± SE.
Coarse root was defined as ≥2 mm and < 5 mm in diameter.