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Autotrophic and heterotrophic respiration of a poplar plantation chronosequence in northwest China

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ABSTRACT

The partitioning of soil respiration is helpful for understanding the mechanism of soil CO_2 production and for estimating net forest C budget. We investigated heterotrophic (Rh) and autotrophic (Ra) components of soil CO_2 efflux (Rs) in a poplar chronosequence (3-, 8-, and 15-yr-old) using a trenching method in 2007 and 2008. Our results showed that Rh and Ra varied with stand age. Mean Rh increased from 1.85 μmol m^{-2} s^{-1} in the 3-yr-old stand to 2.59 μmol m^{-2} s^{-1} in the 15-yr-old stand, while Ra decreased from 3.41 μmol m^{-2} s^{-1} in the 3-yr-old stand to 1.89 μmol m^{-2} s^{-1} in the 15-yr-old stand. There was a significant stand-age effect on Ra. Autotrophic respiration in the three stands all peaked in June, while the maximum Rh and soil temperature occurred in July. The seasonal variations of Ra and Rh could be well explained by soil temperature ($P < 0.01$). The contribution of Ra to Rs during the growing season was 57.1% averaged over the three stands. We found that Rh was positively correlated with dead fine root biomass ($P < 0.01$) and with forest floor litter mass ($P < 0.05$), and that Ra was significantly correlated with live fine root biomass. The root respiration significantly decreased with stand age, which was explained by a decrease in live fine root biomass over the age sequence, whereas the increase of heterotrophic respiration could be attributed predominantly to an increase in the labile C input with stand age. Our results highlight the importance of stand-age effects on different components of soil respiration and its significance to the estimation of forest C sink potential over a rotation.

1. Introduction

Soil respiration (Rs) 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 the soil (Schimel, 1995); globally, soil respiration reaches 50–75 Pg C yr^{-1} (Raich and Schlesinger, 1992), and is therefore an important regulator of climate change as well as a determinant of forest C balance. However, little is known about the respiratory components comprising this emission, mainly due to problems in separating root (usually root and rhizosphere) respiration, generally referred to as autotrophic (Ra), from that of heterotrophic respiration (Rh) (Baggs, 2006).

The partitioning of soil respiration is difficult but important, and it can help us understand forest ecosystem C cycling (Kelting et al., 1998; Ohashi et al., 2000). For instance, calculating C loss through root respiration can help us estimate forest gross primary production more accurately, and heterotrophic respiration must be measured to calculate net forest ecosystem production (Bond-Lamberty et al., 2004). Furthermore, these two components respond differently to soil temperature, exhibiting different Q_{10} values (Boone et al., 1998; Rey et al., 2002), and thereby possibly altering the potential of forest C sequestration (Giardina and Ryan, 2000; Hanson et al., 2000). Thus quantifying the flux and dynamics of each component is vital for examining the nature and extent of feedback between climate change and forest C budget.

The dynamics of these two components are controlled by a range of biotic and abiotic factors including soil temperature, water availability and root biomass (Hanson et al., 2000; Saiz et al., 2006; Yan et al., 2014). Autotrophic respiration is strongly influenced by plant phenology and photosynthetic activities (Högberg et al., 2001; Rey et al., 2002), whereas Rh is fuelled by substrate availability, such as above- and below-ground litter fall and the soil organic carbon content (Wang and Yang, 2007). Furthermore, previous studies indicate that the relative contribution of Ra to soil CO_2

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efflux (RC) ranges from 10% to 90%, depending on the season, root growth and vegetation type (Boone et al., 1998; Hanson et al., 2000). Defining main factors controlling each component and attaining a reliable estimation of RC remain the major challenges facing forest C cycle (Baggs, 2006).

Concerns about global climate change have raised expectation that forests can function as sinks for atmospheric carbon via increased carbon sequestration (Lal, 2005). Because of afforestation in the past several decades, poplar plantations in China cover an area of 7 million ha, accounting for 19% of total forest plantation area (Fang, 2008). These poplar plantations serve as a potential carbon sink because of their fast growth and high biomass yield (Arevalo et al., 2010; Dickman and Pregitzer, 1992), and are therefore of great importance to assess forest C sequestration in China.

Stand age plays an important role in ecosystem C budget (Mujuru et al., 2014). To model the long-term forest carbon dynamics and their coupling with the climate system, we should understand the effect of stand age on soil C emission (Saiz et al., 2006; Yi et al., 2007). In forests, a number of structural and physiological changes with tree development are likely to affect the components of soil respiration (Tedeschi et al., 2006). For instance, the quantities of litter fall and root biomass change with stand age (Luan et al., 2011). However, the influences of stand age on the components varied greatly among previous studies (Luan et al., 2011; Saiz et al., 2006; Yi et al., 2007). Detailed information on the effects of stand age on heterotrophic and autotrophic components is necessary.

Trenching is a long-standing method of comparing the soil CO_2 efflux from plots with and without roots (Bowden et al., 1993; Ewel et al., 1987). In this study, trenched plots were used to partition Rs into the autotrophic and heterotrophic components in a poplar chronosequence (3-, 8-, and 15-yr-old) in the growing seasons of 2007 and 2008. The aims of this study were to (1) explore the effects of stand age on Ra and Rh, (2) examine the contribution of Ra to Rs, and (3) determine the Q_{10} values of Rh and Ra.

2. Materials and methods

2.1. Study site

The study area is 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 2800 h. Climate normals for this study site are based on 30 years of meteorological data from local weather station (from 1976 to 2006). 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 (Chinese classification system). Soil texture is typical sandy loam with organic matter content of about 1.2–2.5%, total N of 0.1–0.2%, and pH 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 agricultural lands and have undergone intensive managements, such as irrigation, fertilization and weed control. Due to annual weed control, poplar stands are characterized by an almost absence of understory or sparse herbaceous vegetation such as *Carex liparocarpos*, *Bromus japonicus* and *Achnatherum splendens*. Because poplar plantations depend heavily on water availability, and natural precipitation cannot meet their water demand, irrigation is necessary. Water resources in the farm area are abundant originating from the Yili River, which gives an advantage to plantation development.

2.2. Experimental design

Poplar forests are typically established on 3 m × 4 m spacing in this study, averaging approximately 833 trees ha^{-1}. Three stand age classes (3-, 8-, and 15-yr-old) of a hybrid clone of *Populus deltoids* Bartr., representative of different developmental stages of a rotation, were chosen for this study: 3-yr-old stand, sapling stage; 8-yr-old stand, when canopy was closed, and 15-yr-old stand, close to the end of a rotation cycle. To minimise the sources of error, we selected the stands on sites with identical parent material, landscape position and prior land use history. The stand characteristics of three age classes are given in Table 1. Nine forest plots were selected for this study, with three replicates per stand age. In 20 m × 30 m plots (referred to, hereafter, as the control plots), 6 PVC collars were randomly distributed in each plot, with three of them situated at the base of a sample tree and the others at halfway between two planting rows (Saurette et al., 2006). These collars were inserted into the soil (2–3 cm deep from the ground surface) after removing the herbaceous layer. The sample trees were selected within the borders of each stand to minimise any edge effects. During the growth seasons in 2007 and 2008 (from May to September), all plots were irrigated monthly, with approximately 35–40 mm of water.

To separate Rh from Rs, the trenching technique was employed. An additional plot (0.5 m × 0.5 m) with a distance of 4–5 m from control plot was established, and a trench 0.2 m wide and 75 cm deep around the plot was dug in April 2007. After lining the trench with polyethylene net of 0.08 mm mesh size, the soil was refilled into the trench according to its original soil profile. One soil collar was located on the centre of the trenched plot. The live roots extending into the plots were cut down. The additional plots were then kept free of seedlings and herbaceous vegetation by periodic manual removal.

2.3. Measurement of the Rs and soil environmental factors

The soil respiration was measured with a Li-6400 portable CO_2 infrared gas analyser (IRGA) equipped with a Li-6400-09 chamber (Li-Cor, Inc., Lincoln, NE, USA). During the growing seasons in 2007 (from May to September) and 2008 (from May to July), soil respiration was measured once per month in the control and trenched plots during 10:00 am and 16:00 pm. The measurements began on the third day after irrigation to avoid the influence of excessive soil water.

Soil temperature was monitored simultaneously with Rs measurement using a constantan thermocouple penetration probe (Li6000-09 TC, Li-Cor, Inc.), inserted into soil to a depth of 5 cm in the vicinity of the PVC chamber. Soil water content adjacent to

Table 1
Stand characteristics of poplar plantations at three ages. The data are mean ± SE.

Parameters	3-yr-old	8-yr-old	15-yr-old
Canopy coverage (%)	70	85	80
Mean tree height (m)	8.8 ± 0.8	17.3 ± 0.7	20.7 ± 0.5
Mean diameter at breast height (cm)	10.9 ± 1.2	19.2 ± 1.5	24.3 ± 1.8
Stand density (stem ha^{-1})	833	833	833
Forest floor litter mass ($g\ m^{-2}$)	288.7 ± 18.5	517.3 ± 28.7	823.7 ± 36.2
Available *P* ($mg\ kg^{-1}$)	5.65 ± 0.54	5.26 ± 0.38	5.52 ± 0.45
Available *K* ($mg\ kg^{-1}$)	210.63 ± 16.4	256.05 ± 13.2	292.83 ± 11.7
pH	8.30 ± 0.06	8.33 ± 0.03	8.36 ± 0.02