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Ecosystem carbon exchange over a warm-temperate mixed plantation in the lithoid hilly area of the North China

Xiaojuan Tong [a,b], Ping Meng [a,*], Jinsong Zhang [a], Jun Li [c], Ning Zheng [a], Hui Huang [a]

[a] Key Laboratory of Tree Breeding and Cultivation of State Forestry Administration, Research Institute of Forestry, Chinese Academy of Forestry, Beijing 100091, China
[b] The Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University, Beijing 100083, China
[c] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

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ABSTRACT

In recent decades, forest area in China increased rapidly by afforestation and reforestation, especially in its temperate parts. However, lack of information on carbon exchange in temperate plantations in China reduced the accuracy of estimation on regional carbon budget. In this study, CO_2 flux was measured using the eddy covariance method over a broadleaf dominant mixed plantation in the lithoid hilly area of the North China. The results showed that annual maximum photosynthetic capacity (A_{max}) varied from 0.81 to 1.22 mg CO_2 m^{-2} s^{-1} and annual initial light use efficiency (α) from 0.014 to 0.026. Net CO_2 uptake was depressed when vapor pressure deficit (VPD) was more than 2.5 kPa. Annual temperature sensitivity coefficient (Q_{10}) for ecosystem respiration, ranged from 1.84 to 2.35, was negatively correlated with base ecosystem respiration (R_0) ($P < 0.05$). Annual R_0 decreased but Q_{10} increased evidently when winter drought occurred. From 2006 to 2010, annual net ecosystem carbon exchange (NEE), Gross primary productivity (GPP) and ecosystem respiration (R_{ec}) were -355 ± 34, 1196 ± 21 and 841 ± 43 g C m^{-2} yr^{-1}, respectively. The warm-temperate mixed plantation in the lithoid hilly area of the North China was a strong carbon sink of the atmosphere, which was usually weaken when spring drought happened.

1. Introduction

Forests play an important role in terrestrial carbon cycle and global climate change. During the 20th century, forest areas generally increased in temperate regions by afforestation, but decreased in tropic areas due to deforestation. In recent three decades, the impacts of afforestation and reforestation on global terrestrial carbon sink are insignificant (IPCC, 2007). Nevertheless, regional carbon sinks have increased in the areas such as China, where afforestation and reforestation since the 1970s has sequestered 0.45 Gt C (Fang et al., 2001). The investigations on carbon sequestration by the plantations are very important for estimating the regional carbon budget.

The effective method understanding the variability in carbon sink/source functions of forests is directly measuring net carbon exchange between forests and the atmosphere. The eddy covariance technique provides a useful tool to obtain long-term carbon flux data and to evaluate the role of forests in global carbon cycle (Oechel et al., 2000; Baldocchi et al., 2001b). Net ecosystem CO_2 exchange (NEE) between the biosphere and the atmosphere is the balance between assimilatory and respiratory fluxes. Gross primary productivity (GPP) is strongly dependent on light during the growing season when temperature is adequate for growth, whereas ecosystem respiration (R_{ec}) is strongly dependent on temperature and moisture (Falge et al., 2002). Shifts in the relative contribution of assimilation and respiration to total fluxes could affect future ecosystem carbon sequestration potentials, and the stability of stored carbon (Alward et al., 1999). The interplay between assimilation and respiration determines the diurnal and seasonal patterns, in phase and amplitude, of net ecosystem carbon flux (McCaughey et al., 2006; Carrara et al., 2004). Inter-annual variability in net ecosystem productivity is driven by temperature (Carrara et al., 2003; Zha et al., 2009) and the length of growing season (Black et al., 2000; Goulden et al., 1998; Baldocchi et al., 2001a; Meyers, 2001; Carrara et al., 2003). Water availability limits leaf area index (LAI) over the long-term, and inter-annual climate variability can limit carbon uptake below the potential of the leaf area present (Law et al., 2002).

In China, forest area enlarged obviously by afforestation and reforestation in recent decades. Up to 2009, plantations in the

* Corresponding author.
E-mail addresses: tongxjsxbs@sina.com (X. Tong), mengping@caf.ac.cn (P. Meng).

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North China occupied 8.21 million ha, accounted for 13% of the total plantation area in China (Jia, 2009). Most of them were located in the lithoid mountain regions, with thin and barren soils. However, the tall trees grew in these areas present a potential carbon sink in the plantations. Based on biometric measurements, Fang et al. (2007) reported that net ecosystem productivity (NEP) in a warm-temperate pine plantation was 408 kg C m^{-2} yr^{-1}. In China, compared with the studies in temperate, subtropic and tropic regions (e.g. Guan et al., 2006; Wen et al., 2010; Zhang et al., 2010), the researches on forest carbon fluxes in warm-temperate regions were scarce. Lack of carbon flux measurements for the forest in these areas reduced the accuracy of estimation on regional carbon budget. In this study, the eddy covariance method was used to measure CO_2 flux over a broadleaf dominant mixed plantation in the lithoid hilly area of the North China. The objectives were: (1) to quantify the carbon sink strength of the mixed plantation, (2) to investigate the temporal variability in NEE, GPP and R_{ec}, and (3) to characterize their responses to the environmental factors.

2. Material and methods

2.1. Site description

CO_2 flux was measured using eddy covariance method in a broadleaf dominant mixed plantation of Yellow River Xiaolangdi forest experimental station (35°01′N, 112°28′E; elevation 410 m). The station is located at the lithoid hilly area of the North China, adjacent to the south of Taihang Mountain and the north of Yellow River Basin, with a warm-temperate continental monsoon climate. In recent three decades, annual mean temperature is 13.4 °C, and annual precipitation is 642 mm. The amount of rainfall from June to September accounts for 68% of whole year. In this region, seasonal drought especially in spring is serious. The main wind direction from May to September is northeast and southwest. The soil parent material is composed of limestone. The soil is mainly brown loam, with a thin layer (averaged 40 cm in thickness) and low soil nutrient content.

The plantation is composed by cork oak (*Quercus variabilis blume*) (80%), black locust (*Robinia pseudoacacia* L.) (12%) and arborvitae (*Platycladus orientalis*) (8%), with ages of 32, 28 and 30 years old and heights 10.5, 9.3 and 8.2 m, respectively. The understory is dominated by sour jujube (*Ziziphus jujuba* Mill. var. *inermis* (Bunge) Rehd.), bunge hackberry (*Celtis bungeana* Bl.), green bristlegrass herb (*Setaria viridis* (L.) Beauv.), and sowthistle-leaf ixeris (*Ixeris sonchifolia* Hance). The flux tower (36 m) is situated at the center of a large area of the plantation (7210 ha). The tree density was 1905 stems ha^{-1} and the coverage is about 96%. In the growing season, mean LAI for the mixed plantation is about 6.3. Mean slope of the area around the flux tower (about 1.8 km^2) is 14°. The topographic map of the flux observation site is shown in Fig. 1.

2.2. CO_2 flux and microclimate measurements

The eddy covariance system consisted of a three-dimensional sonic anemometer (model CSAT3, Campbell Scientific Inc., USA) and an open-path and fast response infrared CO_2/H_2O analyzer (IRGA, Model LI-7500, Li-Cor Inc., USA), which can be used to measure 3-D wind speed, air temperature, air humidity and CO_2 concentration above the canopy. Both instruments were installed at a height of 30 m. Raw data were collected at 10 Hz and recorded by a CR5000 datalogger (Model CR5000, Campbell Scientific Inc., USA).

Air temperature and relative humidity were measured with shielded and aspirated sensors (Model HMP45C, Campbell Scientific Inc.) at heights of 8, 9, 11, 14, 18, 26 and 30 m, respectively. A pyranometer (Model CM11, Kipp & Zonen, Delft, The Netherlands) and a net radiometer (Model CNR-1, Kipp & Zonen, Delft, The Netherlands) were installed at a height of 27 m. In addition, photosynthetically active radiation (PAR) and precipitation were measured with a quantum sensor (Model LI190SB, Li-cor, Inc., USA) and a rain gauge (Model 52203, RM Young Inc., Michigan, USA), respectively. Soil temperature sensors were placed at the depths of 0, 5, 10, 15 and 20 cm. Soil moisture at a depth of 20 cm was measured by time domain reflectometry (TDR) probes (Model CS615-L, Campbell Scientific Inc., USA). Soil heat flux at a depth of 5 cm was monitored at four points around the tower (Model HFT-3, Campbell Scientific Inc., Logan, UT, USA). All above instruments were controlled by dataloggers (Model CR10XT and CR23XTD, Campbell Scientific Inc., USA) and mean data were stored at 30 min intervals. LAI was measured with a plant canopy analyzer (LAI-2000, Li-cor, Inc., Lincoln, Nebraska, USA) from April to October.

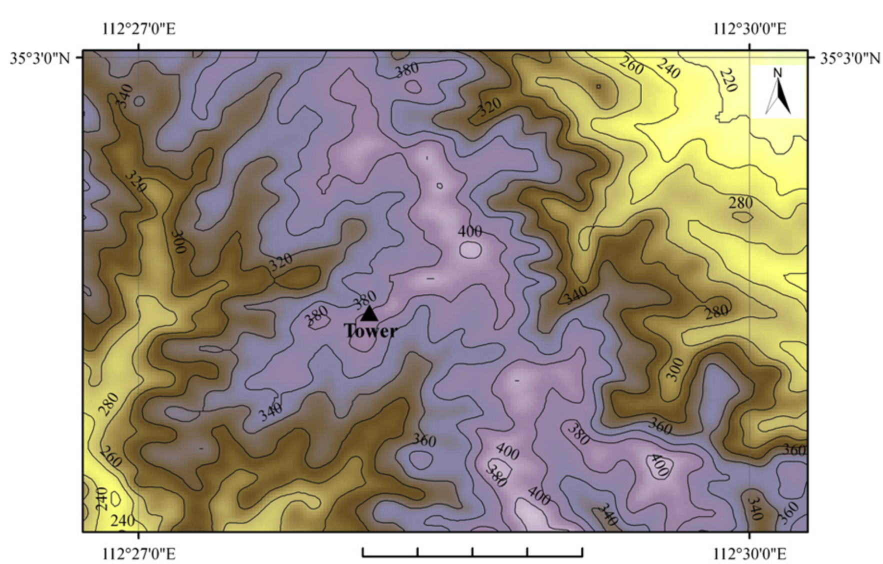

Fig. 1. The topographical map of flux observation site in Yellow River Xiaolangdi forest experimental station, with 20 m equidistance lines.