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Seasonal variation of carbon exchange from a revegetation area in a Chinese desert

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ABSTRACT

Revegetation is a common method to combat desertification and to reduce soil carbon loss in arid and semi-arid areas worldwide. Revegetated areas in the temperate arid Shapotou area of Northern China were established to stabilize sand dunes in an area subject to wind erosion. The objective of this study was to characterize the carbon flux of a 20-year old revegetated area. During the measurement period from May 2008 to December 2010 carbon flux was measured by the eddy covariance technique, and rainfall, temperature, and soil water content were monitored simultaneously with the aim of understanding the relationship between carbon flux and meteorological factors. We found that the revegetated ecosystem is a carbon sink during the growing season when most of the annual precipitation falls. The revegetated area changed from being a carbon source to a sink in the 1 or 2 days following an effective rainfall event. In the non-growing season the ecosystem was a carbon source. The soil water content (SWC) affected the relationship between ecosystem respiration and temperature. The nighttime respiration rate increased with soil temperature. When the SWC was ≥3% the correlation between respiration rate and soil temperature was stronger ($R^2 = 0.23$) than when SWC was <3% ($R^2 = 0.08$). Although the net ecosystem carbon flux (NEE) in temperate arid desert areas is relatively small compared to that of humid areas, it represents huge carbon fixation potential because of the very large area of desert in northern China. Further research is required to clarify the effects of climatic factors on the various components of temperate arid ecosystems, especially the roles of cryptogam and biological soil crusts in the carbon exchange processes.

1. Introduction

Arid and semi-arid regions cover more than one-third of the Earth's surface, making these systems the largest biome type in the world (Schlesinger, 1991; Reynolds, 2001). Net primary productivity (NPP) in these regions is estimated to comprise approximately 20% of total terrestrial NPP (Whittaker, 1975), and the total soil organic carbon (SOC) pool in soils of the drylands is approximately 15% of global soil organic carbon (Schlesinger, 1991; Lal, 2004). The vast areas of arid and semi-arid regions mean they play an important role in the global carbon cycle (Lal, 2004). Since validation of the Kyoto Protocol, the vegetation restoration or revegetation in these regions seems to be a way to simultaneously sequester carbon for mitigation of climate change and increase wood supply (Vertessy, 2001; Farley et al., 2005).

However, ecosystems in these areas are particularly vulnerable to environmental constraints and human activities (Puigdefábregas and Mendizábal, 1998). Research has shown that increases in temperature and shifting precipitation patterns associated with climate change will result in changes in the structure (e.g. vegetation composition) and functions (e.g. carbon assimilation) of many arid ecosystems (Midgley et al., 2004), and shifts from being carbon sources to sinks (McGuire et al., 1995; Raich and Schlesinger, 1992; Rustad and Fernandez, 1998). In addition, the extent of arid lands may increase dramatically as a result of climate change (Schlesinger et al., 1990; Maestre and Cortina, 2004a). Climatic changes associated with increases in atmospheric CO_2 concentration could result in an increase of desert areas by 17% (Emanuel et al., 1985). Considering the large extent of arid and semi-arid ecosystems an increase or decrease in these lands may have significant effects on the global carbon balance and climate change (Hastings et al., 2005).

Revegetation is a common method to combat desertification and to prevent soil carbon loss in arid and semi-arid areas worldwide (Ffolliott et al., 1995; Gao et al., 2002). Although restoration

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methods by revegetation vary with natural and economic conditions (Gao et al., 2002), the reintroduction of woody or shrub species in plantations has become increasingly important in degraded arid and semiarid lands (Castillo et al., 1997). The importance of vegetation restoration may also increase in the future due to its role in carbon sequestration in arid and semiarid areas (Keller and Goldstein, 1998).

Some researchers concluded that monoculture plantations could result in an increase in water use, a decrease in biodiversity, and limited carbon fixation, compared with more natural mixtures of local indigenous shrubs (Maestre and Cortina, 2004b). Monoculture plantations of exotic trees have been described as "green deserts" due to the lack of biodiversity and less carbon sequestration in comparison with more diverse revegetation efforts (Maestre et al., 2001). Further research is required to evaluate the ecological effects and carbon sequestration potential of revegetated areas because the practice has been controversial over the last few decades.

China is one of the most desertified countries in the world (Wang et al., 2004) and has paid great attention to ecological restoration in its arid and semiarid desert regions. A series of ecological engineering projects has been established to reduce and combat desertification in northern China (Li et al., 2004a; Wang et al., 2007). To date, vegetation restoration covers more than 2.4 million hectare of degraded land in China and includes revegetation by sand-binding species in desert regions to reduce the impacts of desertification (Li et al., 2004b). However, little information has been obtained on the contribution of the vegetation to carbon fixation.

The establishment of sand-binding vegetation in the Shapotou region is considered a successful example of the control of moving sand (Xiao et al., 2003). Xerophytic shrubs were planted in the Shapotou region at the southeastern fringe of the Tengger Desert in order to protect the Baotou–Lanzhou railway line from sand burial by the mobile dunes. Long-term monitoring indicated that stabilization of the windblown sand benefits from the establishment of grasses and cryptogam, while shrubs began to retreat after about 20 years of revegetation. After 50 years of succession, the mobile dune-dominated desert landscape changed into a complex modified natural desert ecosystem (Li et al., 2000). The amount of fine particles, total N, P, K and organic matter increased significantly in the topsoil (Li et al., 2007), and the development of biological soil crusts is regarded as an important feature in the succession. Compared to the original sand dunes, soil respiration has increased dramatically due to the presence of plant roots and the establishment of micro-organisms (Gao et al., 2009b). However, no information is available on the net ecosystem exchange of CO_2 in the areas stabilized by revegetation. Research on this issue could contribute to our understanding of the effects of carbon sequestration associated with revegetation in desert areas.

In this paper we report the net ecosystem carbon flux (NEE) in a revegetated area at the southeast fringe of the Tengger Desert with specific objectives of quantifying the magnitude of CO_2 exchange, and to identify the seasonal variation of CO_2 exchange at the time scales of both half-hour and month.

2. Experiment site and methods

2.1. Experiment site

This study was conducted at the Shapotou Desert Research and Experimental Station. Shapotou is located at the southeast edge of the Tengger Desert in north-central China (37°32′N, 105°02′E) with an elevation of 1288 m. The area is a typical ecotone between

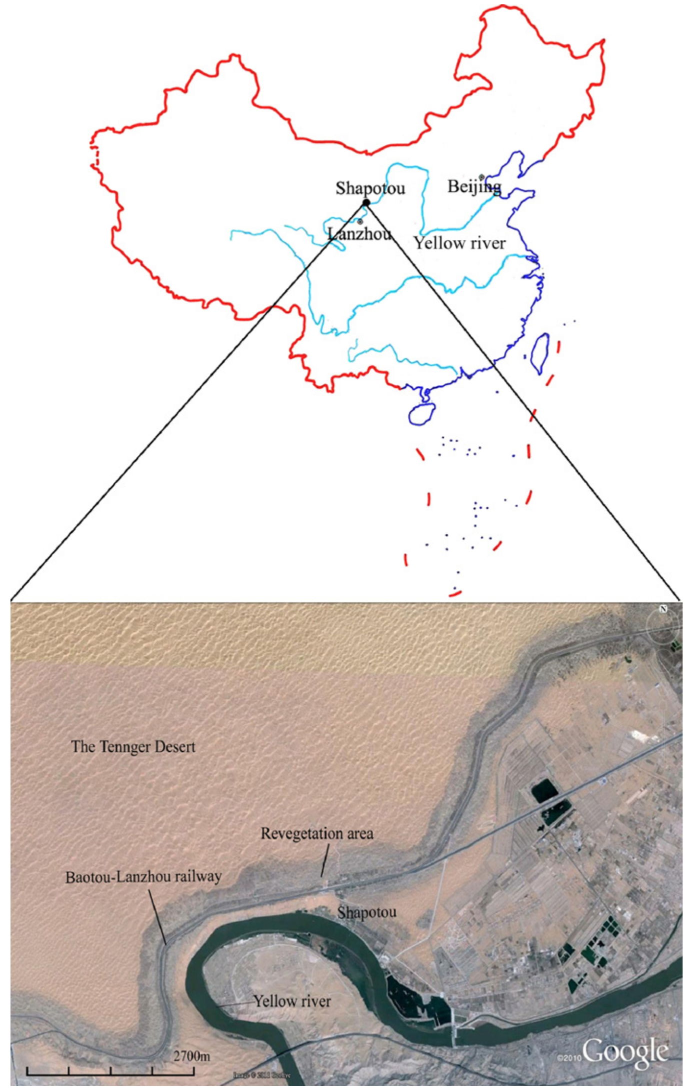

Fig. 1. Diagram showing the revegetation area at the Shapotou region of the Tengger Desert, China.

steppe desert and sandy desert, where the natural vegetation is dominated by *Hedysarum scoparium* and *Agriophyllum squarrosum* with an approximate 1% cover (Li et al., 2004c). The area is characterized by sandy, high, dense and continuous reticulate barchan dunes. According to meteorological records from the Shapotou Weather Station from 1955 to 2005, mean annual temperature was 10.6 °C, with minimum and maximum mean daily temperatures of −6.3 °C in January and 24.9 °C in July, respectively. Average wind velocity was 2.6 m s^{-1}, and the mean annual number of days with dust events is 122. Mean annual precipitation is 186 mm, most of which falls between June and September.

Rain-fed vegetation was established in 1956 by planting of xerophytic shrubs to prevent the burial of the Baotou–Lanzhou railway line from sand as it passes through the mobile sand area. The main species planted included the indigenous shrubs *Caragana korshinskii* and *Artemisia ordosica*. Details of the revegetation were described by Li et al. (2004c). The revegetation area was further expanded in 1964, 1973, 1981, 1987 and 1989 using the same methods. A 500 m wide belt of sand-binding vegetation was established on the north side of the railway and a 200 m wide belt of sand-binding vegetation was established on the south side of the railway, with a total length of 16 km (Fig. 1). After the shifting sand became fixed the generation of biological soil crusts occurred on