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CO_2 Fluxes of Alpine Shrubland Ecosystem on the North-eastern Tibetan Plateau

By

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Summary

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We measured ecosystem CO_2 fluxes for an alpine shrubland on the north-eastern Tibetan Plateau, Qinghai, China. The study is to understand (1) the seasonal variation of CO_2 flux and (2) how environmental factors affect the seasonality of CO_2 exchange in the alpine ecosystem. Daytime ecosystem respiration was extrapolated from the relationship between temperature and nighttime CO_2 fluxes under high turbulent conditions.

Seasonal patterns of gross ecosystem production, ecosystem respiration and net ecosystem CO_2 exchange followed highly the seasonal change of aboveground biomass in the alpine shrubland. The net ecosystem CO_2 exchange was mainly controlled by the variation of photosynthetic photon flux density, while the ecosystem respiration was closely correlated to the soil temperature at 5-cm depth. Integrated values of gross ecosystem production, ecosystem respiration and net ecosystem CO_2 exchange for the period from November 1, 2002 to October 31 2003 were estimated to be 1418, 1155 and 222 g CO_2 $m^{-2}yr^{-1}$, respectively.

These results indicate that aboveground biomass is the major determinant for the ecosystem CO_2 exchange, while soil temperature at 5-cm depth determines the ecosystem respiration of the alpine shrubland. The study also suggests that the alpine shrubland ecosystem is currently a net CO_2 sink.

Introduction

Grasslands cover about one-fifth of the total global terrestrial area (ADAMS & al. 1990). It is therefore essential to clarify the contribution of the extensive eco-

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systems to the global carbon budget (FRANK & al. 2002). In east Asia, grasslands cover even more extensive area, which reaches more than 40% of the total terrestrial area in China (ZHAO & ZHOU 1999). However, little data are available for us to assess the carbon budget of grasslands in the area.

The Qinghai-Tibetan Plateau extends more than 2.5 million square kilometres GU & al. 2005). The plateau is covered by various grassland ecosystems including alpine meadow, alpine shrubland meadow and alpine steppe. Among these ecosystems, alpine shrubland is considered to play a key role in carbon storage on the extensive plateau. Because of the high altitude, the shrubland ecosystem is also very fragile and sensitive to global climate changes (ZHAO & ZHOU 1999). The alpine ecosystem is also characterized by high soil organic content and low mineralization (CAO & al. 2004). It is interesting to know how the large carbon pool changes under climate change in the future. All these result in an increasing attention on the global change biology for the unique plateau.

The main objective of this current study is to understand (1) the seasonal variation of CO_2 flux, and (2) how environmental factors affect the seasonality of carbon exchange in the alpine shrubland on the Qinghai-Tibetan Plateau.

Material and Methods

Eddy covariance method with an open path CO_2 analyzer (IRGA, Model LI-7500, LI-COR, Inc., Lincoln, NE) was used for the examination of ecosystem CO_2 flux in an alpine shrubland (37°29'N, 101°12'E) at the north-eastern edge of the Qinghai-Tibetan Plateau. The average altitude of mountain area is about 4000 meters above sea level but the elevation ranges from 2900 to 3500 meters in the valley area. The climate of the region is dominated by southeast monsoon and high pressure of Siberia. It has a continental monsoon type climate with severe and long winter period, but short and cool summer season. The average annual air temperature is -1.7°C with the annual maximum of 27.6°C and the annual minimum of -37.1°C during last 20 years (GU & al. 2004). The annual precipitation ranges from 426mm to 860 mm with 80% of which falls in the summer growing season from May to September. The annual average sunlight is 2463 hours with 60% of total available sunshine (ZHAO & ZHOU 1999).

The shrubland is dominated by *Potentilla fruticosa* and accompanied with shrubby *Salix* species, which is frequently found in those habitats with high soil water availability. In contrast to the meadow ecosystem in the area, the alpine shrubland on the Qinghai-Tibetan plateau is often used as the summer pasture because it is located at relatively high elevations.

The eddy covariance tower was set up in October, 2002. A three-dimensional sonic anemometer (Model CSAT3, Campbell Scientific, Inc., Logan UT) and an open path infrared gas analyzer were mounted at a height of 2.5m at the top of a scaffolding tower to measure the three components of the wind velocity vector, sonic temperature, and the densities of water vapor and CO_2. All the data were sampled at 20 Hz by a data-logger (CR5000, Campbell Scientific, Logan, UT), which were calculated as 30 min covariance using block Reynolds averaging. Surface fluxes were later calculated off-line after performing a two-dimensional coordinate rotation and accounting for density fluctuations (WEBB & al. 1980). The sonic temperature was used to calculate sensible heat flux using the method suggested PAW & al. 2000, which accounts for a missing energy balance term associated with the expansion of air during evaporation under constant pressure. Soil moisture was measured with 6 water content meters (Model CS615, Campbell Scientific, Inc., Logan, UT) installed in profiles at depths of 0.05, 0.10, 0.15, 0.20, 0.40 and 0.80 m.

Data from all the sensors were recorded on data loggers (Models CR23X and CR5000, Campbell Scientific, Inc., Logan, UT), which were interrogated every 30 days by a laptop PC. The flux observation sites had a sufficient wide fetch at least 1km in all directions.

For long-term and continuous field measurements. missing data is unavoidable due to malfunction of the instrumentations or power failure. The missing data during the growing season were filled by using a rectangular hyperbolic light-response function (FALGE & al. 2001) when U* exceeded 0.15 ms^{-1}:

$$NEE = R_{eco} + (P_{\max} * \alpha * PPFD)/(\alpha * PPFD + P_{\max}) \quad (1)$$

where *PPFD* is incident photosynthetic active flux density, $P_{\max}$ the maximum net CO_2 flux at infinite light, α the apparent quantum yield, and R_{eco} the respiration from soil and plants. Nighttime missing data were filled by using the following exponential relationship between *F*c from periods of high turbulence when the friction velocity U^* was higher than 0.15 ms^{-1} and soil temperature at depth of 5cm (T_{soil}):

$$NEE = b_0 * \exp(b_1 * T_{soil}) \quad (2)$$

where b_0 and b_1 are two empirical coefficients, from which Q_{10} can be estimated as

$$Q_{10} = \exp(10^{b_1}) \quad (3)$$

The SAS software was used to treat data and nonlinear produces with Newton-Gauses method was employed to estimate the parameters (SAS 8.0).

Results and Discussion

During the growing season from May to October, the relationship between daytime carbon flux and photosynthetic photon flux density (PPFD) followed a typical rectangular hyperbolic curve (Fig. 1). The maximum of net ecosystem CO_2 exchange rate (NEE) during the growing season was about 2.223 $gCO_2\ m^{-2}\ h^{-1}$. In July and August, NEE decreased slightly when PPFD exceeded 1500 $\mu mol\ m^{-2}\ s^{-1}$. The result was consistent with that reported for an alpine meadow close to the current study (GU & al. 2004, KATO & al. 2004). The decrease of NEE under high radiation could be resulted from (1) the reduction of photosynthetic CO_2 uptake by photoinhibition, (2) the increase of ecosystem respiration under high temperature accompanied with high radiation. Further studies are needed to clarify the eco-physiological mechanisms.

We further examined the maximum NEE using the Eq. (1) and found that it varied from 0.986, 1.999, 2.223 to 1.1567 g $CO_2\ m^{-2}\ h^{-1}$ from June, July, August to September, respectively. The high maximum NEE indicates that the alpine shrubland may have high potential in CO_2 uptake during the growing season. A recent study on the carbon dynamics of *Kobresia* meadow on the same plateau suggest similar possibility (KATO & al. 2004).

Ecosystem respiration (R_{eco}) was all highly correlated with soil temperature for both growing season and winter season (Fig. 2). R_{eco} showed high values from July to August, but low values from January to February when the average soil

temperature decreased to values around -10°C. The Q_{10}, an indicator of temperature sensitivity of soil respiration, was 2.08 and 7.24 for the growing and winter season,

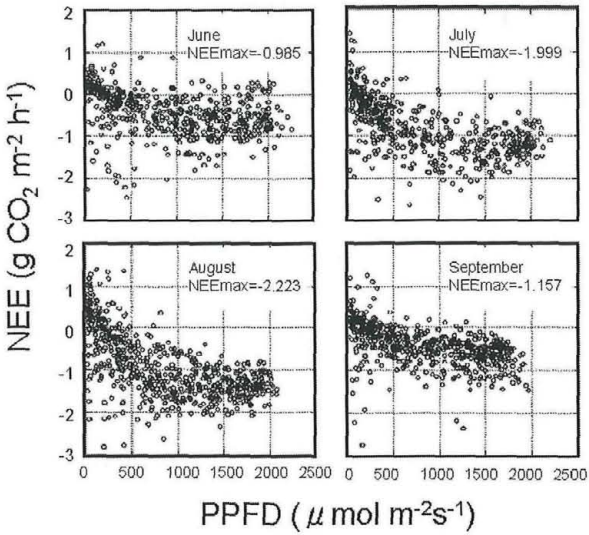

Fig. 1. Relationship between net CO_2 exchange and photosynthetic photon flux density (PPFD) in an alpine shrubland on the Qinghai-Tibetan Plateau during the growing season.

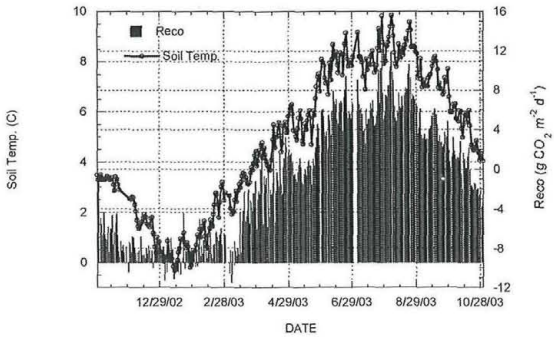

Fig. 2. Seasonal variation of soil temperature at 5-cm depth and ecosystem respiration (R_{e-co}) in an alpine shrubland in 2002.

respectively (Fig. 3). High Q_{10} values from the present study were observed in winter season whereas low values were found during the growing season. This suggests the importance of winter CO_2 flux in response global warming (FAHNESTOCK & al. 1999). The result also indicates that the response of ecosystem respiration to temperature was more sensitive in low temperature than in high temperature, which

is similar to a recent report from an alpine meadow on the plateau (KATO & al. in press).

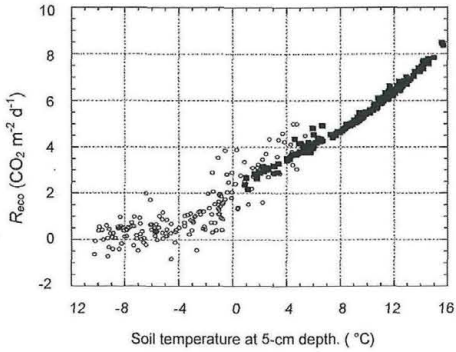

Fig. 3. Response of ecosystem respiration (Reco) to soil temperature at the depth of 5 cm for the winter season(○) from November to April of next year and the growing season (■) from May to October.

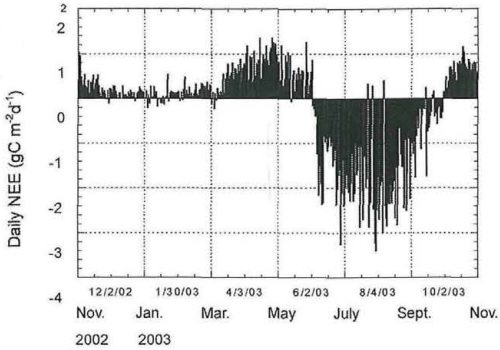

Fig. 4. Seasonal variation of daily net ecosystem carbon exchange (NEE) from DOY305 (1 Nov. 2002) to DOY304 (31 Oct. 2003).

Seasonal variation of NEE from 2002 to 2003 was distinct (Fig. 4). Two large carbon release peaks appeared in May and October, respectively. A significant carbon uptake by the ecosystem occurred during the growing season from June to September. The seasonal pattern of NEE was similar to those observed by KATO & al. 2004 and CAO & al. 2004 for an alpine meadow ecosystem in the same area. The detailed biochemical and physiological mechanisms underlie the seasonal pattern, however, still remained to be clarified in the future. Based on the annual change of NEE, the CO_2 absorbed by the shrubland ecosystem from atmosphere was estimated to be about 70 gC $m^{-2}year^{-1}$, which indicates a moderate carbon sink (HOUGHTON & al. 2001).

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