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Seven years of carbon dioxide exchange over a degraded grassland and a cropland with maize ecosystems in a semiarid area of China

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ABSTRACT

Based on eddy covariance measurement over a degraded grassland and a cropland with maize (*Zea mays*) ecosystems from 2003 to 2009, carbon exchange processes and their responses to environmental factors in different temporal scales were analyzed in semiarid of China. Accounting for carbon export and import, NBP (net biome production) of cropland with maize ranged from 54.3 to 100.6 g C m^{-2} yr^{-1}. NBP remained positive indicating a carbon net loss from this ecosystem although NEE (net ecosystem exchange) was negative in most of years. Due to negligible carbon import and export, NBP of degraded grassland ecosystem was equal to NEE, with an average value of 138.4 g C m^{-2} yr^{-1}. The grassland ecosystem behaved as carbon source during the whole period. PPFD (incident photosynthetic active radiation) was the main driver for diurnal variation of NEE during growing season in most years. NDVI (normal difference vegetation index) was in accordance with seasonal patterns of NEE especially for cropland with maize ecosystem. Soil temperature at a depth of 5 cm was also a main driver for seasonal variation of NEE at the degraded grassland ecosystem in normal precipitation years (2003 and 2005). Annual peak NDVI ($NDVI_{max}$) was significantly correlated with annual NEE and GPP (gross primary productivity). The amount of growing season precipitation was more responsible for annual variation of NEE. The increasing number of precipitation event (>1 mm day^{-1}) was associated with increasing annual carbon uptake. Drought in the early growing period is more critical to carbon dynamics of degraded grassland ecosystem while drought in the middle of growing season was more critical for cropland with maize ecosystem.

1. Introduction

Long-term measurements of CO_2 and water vapor fluxes between the earth's surface and the atmosphere are important to understand the processes controlling carbon cycling across the globe (Baldocchi et al., 2001). Arid and semiarid lands cover as much as one-third of the earth's surface (Verhoef et al., 1999), and the extent of arid and semiarid lands may increase in response to climate change (Emanuel et al., 1985). Ecosystems in semiarid areas are prone to soil degradation, which may be aggravated by land use and climate change (Domingo et al., 2011). Although there are many studies on carbon exchange of ecosystems in semiarid area (Huxman et al., 2004; Huang et al., 2008; Zhang et al., 2011; Liu and Feng, 2012), further investigations are needed to quantify the carbon balance and the response of different land use types to climate variability in this area.

Grasslands are found most commonly distributed in semiarid zones (28% of the world's grasslands) (Robin et al., 2000). Large uncertainties remain in resolving whether these ecosystems function as CO_2 sources or sinks (Baldocchi et al., 2001). At the ecosystem scale, grassland can act as net carbon source or sink or transfer between them (Suyker et al., 2003; Ma et al., 2007; Marcolla et al., 2011). Previous researches on grassland carbon exchange have shown the variability of carbon balance on dependence of annual precipitation (Suyker and Verma, 2001; Knapp et al., 2002) or timing and amount of precipitation (Ma et al., 2007) or length of growing season (Xu and Baldocchi, 2004). Additionally, croplands are the most intensively and frequently managed land-use type and, thus it is very difficult to predict their carbon sequestration strengths (Zhang et al., 2007). Agro-ecosystems are important in China where the cropland biome covers the third largest area (Liu et al., 2005) and they have been reported as carbon contributors to regional carbon budget (Lei and Yang, 2010). Nitrogen is an essential nutrient for all natural and managed ecosystems. More recent studies have focused on assessment of the nitrogen budget and the impact of nitrogen contents on carbon cycling over grassland and cropland ecosystems (Ammann et al., 2009; Loubet et al., 2011). However, the nitrogen budget was not considered here, as it's difficult to directly measure components of nitrogen fluxes.

Precipitation may be the critical factor affecting productivity and carbon sequestration of semiarid regions (Vargas et al., 2012).

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The effect of precipitation events on carbon balance depends on a complicated interaction of current soil water condition, timing and magnitude of precipitation, soil type and texture, plant and soil communities, and evaporative demand (Parton et al., 2012). Droughts are the main source of inter-annual variation in terrestrial carbon sequestration, reducing both productivity and net ecosystem carbon exchange (Ciais et al., 2005). Variation in the timing and amount of the precipitation, and intervals between precipitation events, are crucial in determining the pulse effects on productivity and respiration in semiarid area (Jongen et al., 2011).

Observations of carbon dioxide and water vapor fluxes suggest that flux responses are likely to vary among different species, soil substrates, and precipitation patterns (Ivans et al., 2006). The response of CO_2 exchange to climatic variation has been found to vary on a temporal scale and across ecosystems (Yang et al., 2011). Only a few CO_2 flux studies have focused on comparison of regional variation (Fu et al., 2009; Du et al., 2012) or different biomes (Stella et al., 2009; Zhang et al., 2011). Multi-years flux measurements produce insights to understand which environmental variables controlling for temporal variations of net ecosystem exchange in different biomes.

In this study we report continuous measurements of carbon dioxide fluxes with eddy covariance method from 2003 to 2009 over a degraded grassland and a cropland with maize ecosystem in a semiarid area of China. The objectives are (1) quantify NBP and temporal variation patterns of NEE and its major components, GPP and Re (ecosystem respiration); (2) determine the major environmental factors controlling for different temporal variation of NEE over two ecosystems; and (3) determine if the amount and distribution of precipitation has a large effect on annual variation of NEE.

2. Materials and methods

2.1. Site description

The observation site is located in a semiarid area of Tongyu county, Jilin Province, China (44°25′ N, 122°52′ E), with a temperate and continental climate. Annual mean temperature (1962–2009) is 5.1 °C. Annual mean precipitation is 377.6 mm, nearly 80% of annual precipitation falling during growing season (May–September). Annual potential evaporation is 1762.9 mm and the relative humidity is 58%. There are no rivers in this region. The average wind velocity of prevailing wind SSW is 4.2 m s^{-1}. The soil is mainly composed of salty alkaline, meadow soil and light chernozem.

There are two kinds of land surfaces for intercomparison, i.e., degraded grassland site and cropland with maize site, with a distance of 5 km away from each other. The degraded grassland was fenced and ungrazed during the study period, without fertilization input. The degraded grassland is mainly covered by *Chloris virgata* community and annual weed community. Grass can reach a maximum height of 10 cm during growing season. The maize is usually sown in early May and harvested completely at the end of September. The maximum height of maize is approximately 1.8 m during the growing season. The cropland is mainly rainy fed over the growing season except for irrigation during seeding time, and receives no organic fertilization (Liu et al., 2008).

The two ecosystems both extend over 2 km and the terrain is fairly flat. The 85% of flux fetch was at the distance of about 500 and 600 m upwind in the unstable condition for the degraded grassland and cropland with maize site, respectively (Liu and Feng, 2012). The fetch is adequate for eddy covariance measurements.

2.2. Measurements and remote sensing

A 20 m tower was established at each site as the observational platform. Air temperature, humidity (HMP45C, Vaisala Inc., Helsinki, Finland) and wind speed (034A, Metone Inc.) were measured at 1.76, 4.36, 8.36, 12.86 and 17.46 m for the degraded grassland and 2.36, 4.36, 8.36, 12.36 and 17.06 for the cropland with maize. Wind directions (014, Metone Inc.) were measured at the height of 17.46 m and 17.06 m for the two sites, respectively. Downward and upward solar (CM21, Kipp & Zonen Inc.) and longwave radiation (CG4, Kipp & Zonen Inc.) were measured above the canopy at a height of 2 m at the degraded grassland and 3 m at the cropland with maize. Soil temperature (STP01_L50, Hukseflux Inc.; 107_L, Cambell Scientific Inc.) at 2, 5, 10, 20, 50 and 80 cm depths and soil volumetric water content (CS616, Cambell Scientific Inc.) at 5, 10, 20, 40 and 80 cm depths were measured. Soil heat flux was measured with soil heat plates (HFP01SC_L50, Hukseflux Inc.) at 5 and 10 cm depths. A tipping-bucket rain gauge (TE525MM; Texas Electronics) was used to measure precipitation near the tower. Due to malfunction or meteorological condition, large gaps in winter occurred. Meantime, precipitation was collected from Tongyu weather station of the China Meteorological Administration, with a distance about 30 km away from the flux tower. It was found that the available measurement of precipitation agreed well with data from the weather station, thus the precipitation data from the weather station was applied instead.

PPFD was derived from solar total radiation data, based on the empirical finding that the proportion of PPFD in solar total radiation was remarkably constant (John, 1976). The ratio of PPFD to solar total radiation was acquired from measurements conducted on a similar grassland ecosystem in Inner Mongolia (43°33′ N, 116°40′ E), an observation site also located in a semiarid area of China (Hao et al., 2008).

Water vapor, CO_2 and energy fluxes were measured continuously using an eddy covariance (EC) measurement system including a 3D ultrasonic anemometer–thermometer (CSAT3, Campbell Scientific Inc., Logan, UT, USA) and an open-path infrared gas analyzer (IRGA, LI-7500, LI-COR Inc., Lincoln, NE, USA). The measured height of the EC system is 2 m at degraded grassland and 3.5 m at cropland with maize. The EC raw data were collected continuously at 10 Hz sampling frequency using a CR-5000 data logger. Slow-response observation data were collected at a sampling interval of 2 S and averaged over 30 min by CR-23X data logger. More details are described in the paper by Liu et al. (2008).

Average 30 min turbulent fluxes were calculated using Edire software (Version 1.5.0.10, R. Clement, University of Edinburgh). Steps for post-processing of the 10 Hz raw data include spike detection, double rotation procedure (McMillen, 1988), spectral loss correction (Moore, 1986), and density fluctuation correction (Webb et al., 1980). Data quality control includes the basic test for the steady state test, and the integral turbulence characteristics test (Foken et al., 2004).

NDVI was used to describe the vegetation canopy of the two sites. NDVI was obtained from the Moderate Resolution Imaging Spectrometer (MODIS) on the EOS-1Terra satellite, with a high resolution of 250 m, at 16-day intervals (Liu and Feng, 2012). Downscaling with atmospheric correction to the two sites has been made before the analysis (Hwang et al., 2011).

2.3. Data processing

Data quality of CO_2 was assessed by a standardized processing algorithms suggested by Papale et al. (2006) based on the post-processing flux data. Half hourly records of CO_2 flux falling outside