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Research Paper

Dual effect of precipitation redistribution on net ecosystem CO_2 exchange of a coastal wetland in the Yellow River Delta

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ABSTRACT

Hydrological regime is crucial in determining the carbon dioxide (CO_2) exchange between the atmosphere and wetlands. Seasonal redistribution of precipitation is one featured hydrological regime shift, but its impacts on ecosystem CO_2 exchange in coastal wetlands remain unclear. Here, based on the eddy-covariance technique, we examined how the net ecosystem CO_2 exchange (NEE) in a coastal wetland of Yellow River Delta in China differed between two years (2012 and 2013) with contrasting seasonal distribution of precipitation. The ecosystem absorbed more CO_2 during the growing stage in 2013 (-268.5 g C m^{-2}) than 2012 (-174.7 g C m^{-2}). This difference resulted from higher NEE in the fast and middle growth stages with different reasons. In the fast growth stage, the higher mean daily NEE occurred due to more precipitation coupled with lower salt stress in 2013 (-6.3 g CO_2 m^{-2} day^{-1}) compared to that in 2012 (-2.2 g CO_2 m^{-2} day^{-1}). During the middle growth stage, the mean daily NEE in 2013 (-4.2 g CO_2 m^{-2} day^{-1}) was significantly higher than that in 2012 (-1.1 g CO_2 m^{-2} day^{-1}) because the ecosystem in 2012 suffered more waterlogged stress. This dual effect of precipitation distribution on vegetation photosynthesis was also observed in a field manipulation experiment at the same site. Our results indicated that the redistribution of precipitation among seasons would play a critical role in regulating ecosystem CO_2 exchange in the coastal wetland. More research on the associated changes between dynamics of soil hydrology and salinity could promote the accuracy of the carbon-budget estimates in coastal wetlands.

1. Introduction

Global climate models project that changes in the frequency and amplitude of extreme meteorological events can result in seasonal redistribution of the precipitation, characterized by fewer and larger precipitation events (Allen and Ingram, 2002; Semenov and Bengtsson, 2002; IPCC, 2007; Knapp et al., 2008). Such changes are expected to continue throughout the current century (Easterling et al., 2000; Min et al., 2011). Drought and flooding caused by the precipitation redistribution could impact soil moisture conditions and profoundly alter the structure, functioning and processes of an ecosystem, including the carbon (C) balance (Hussain et al., 2011; Biederman et al., 2016; Jia et al., 2016). The impacts of drought or flooding caused by the precipitation distribution on the CO_2 exchange of an ecosystem have been studied for a range of ecosystems (Nagy et al., 2007; Noormets et al., 2008; Wu et al., 2011; Scott et al., 2015; Liu et al., 2016), including grassland (Bowling et al., 2015; Sloat et al., 2015), shrubland (Ross et al., 2012; Jia et al., 2016), forest (Bonal et al., 2008; Doughty et al., 2015), mire (Aurela et al., 2007; Leppälä et al., 2011; Lund et al., 2012).

Precipitation may directly or indirectly affect the uptake of CO_2 during photosynthesis and the emissions of CO_2 via respiration as well as decomposition in several different aspects, which subsequently affect NEE (Leppälä et al., 2011; Lund et al., 2012; Doughty et al., 2013; Doughty et al., 2015). On the one hand, the paucity of precipitation can result in little plant growth (Rajan et al., 2013). Compared with the full

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canopy stage, vegetation is most sensitive to droughts during the leaf out and canopy development stages, when the plant's metabolic activity, such as photosynthesis and respiration, can be suppressed by drought (Kwon et al., 2008; Lund et al., 2012; Rajan et al., 2013). On the other hand, when precipitation is excessive and soils become waterlogged, the diffusion of oxygen into soil will be limited. Subsequently, heterotrophic respiration is likely suppressed due to lowered microbial activity and decomposition rates of organic matter (Heinsch et al., 2004). In addition, flooding conditions affect the sensitivity of CO_2 exchange to variations in light and temperature, which in turn influence the uptake of CO_2 in ecosystems (Chivers et al., 2010; Jimenez et al., 2012).

Coastal wetlands, the interfaces between terrestrial and ocean ecosystems, play an important role in the global C cycle by acting as natural carbon (C) sinks (Crooks et al., 2011). Coastal wetlands accumulate organic matter because of their relatively high net primary productivity coupled with a relatively low rate of decomposition of accumulated organic matter (Drake et al., 2015). Most area of a coastal wetland lies beyond the reach of the tides, and its hydrologic regimes is dominated by the interaction of precipitation and a shallow, saline water table in the vertical direction (Zhang et al., 2011; Han et al., 2015). During dry seasons, usually with a limited precipitation supply, water-soluble salts from the groundwater are transported upward to the root zone and soil surface through capillary rise. Exposed to increasing salinity levels, the coastal wetland behaves more as a dryland ecosystem than a wetland (Zhang et al., 2011; Yao and Yang, 2013). During the rainy season, though precipitation can leach salts from the plant root zone, episodic flooding is often observed (Han et al., 2015). The salt accumulation and leaching induced by the seasonal precipitation distribution have a profound impact on the carbon biogeochemical cycle and carbon balance by regulating the salinity and waterlogged stress of plants (Heinsch et al., 2004). Therefore, understanding the responses of NEE to the precipitation distribution is essential not only for predictive modeling of potential short- and long-term changes of carbon storage but also for predicting the possible impacts of climate change. However, the mechanisms underlying the impacts of the precipitation distribution on the ecosystem CO_2 exchange in a coastal wetland have so far received little attention.

The net ecosystem CO_2 exchange (NEE) between an ecosystem and the atmosphere relies on the balance between CO_2 uptake through plant photosynthesis and ecosystem respiration through plant and soil respiration (Iii et al., 2006). The micrometeorological eddy covariance (EC) technique has been widely used to quantify NEE between the atmosphere and the vegetation surface in various wetlands because it can provide continuous, long-term flux information integrated at the ecosystem scale (Aubinet et al., 1999; Baldocchi et al., 2001; Baldocchi, 2008; Ross et al., 2012). Using eddy covariance, our study was conducted in a coastal wetland of the Yellow River Delta, where the hydrologic regimes are dominated by the interaction of precipitation and a shallow, saline water table in the vertical direction. Fortuitously, the amounts of rainfall in 2012 and 2013 were similar, but the precipitation distributions during the different growing stages were significantly different. This offers a special opportunity to investigate the impact of the precipitation distribution on CO_2 exchange in a coastal wetland. The main objectives of this study were to assess the effect of the precipitation distribution on the magnitude of NEE and its light and temperature response in a coastal wetland.

2. Materials and methods

2.1. Site description

The study was conducted in the Yellow River Delta Ecological Research Station of Coastal Wetland (37°45′50″N, 118°59′24″E), which belongs to Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences. The flux tower is located approximately 3 km south of the Yellow River channel and approximately 20 km southwest of the mouth of the Yellow River. The experimental site has a warm temperate and continental monsoon climate with distinctive seasons and distributions of rain and heat. The annual average temperature is 12.9 °C, and the average annual precipitation is 550–640 mm, with nearly 74% of the precipitation falling between June and September. The prevailing wind direction in the growing season is from the northeast to the southeast (Han et al., 2013). The soil type in the Yellow River Delta gradually varies from fluvo-aquicto saline soil, and the soil texture is mainly sandy clay loam. Due to the flat terrain and high groundwater table, the entire area is covered mainly by wet and saline soil (Nie et al., 2009). In most of the areas, the groundwater levels range from 1 to 3 m with high water salinity (5–30 g L^{-1}) (Min et al., 2009; Fan et al., 2011), which is affected by fresh water and salt water (Guan et al., 2001; Fan et al., 2011; Zhang et al., 2011; Zhong et al., 2013).

The vegetation is relatively homogeneous and strongly dominated by common reed (*Phragmites australis*), with other associated species including *Tamarix chinensis*, *Tripolium vulgare*, *Suaeda salsa* and *Imperata cylindrical*. The growth stages of the natural growth cycle (DOY 97–311) were divided from the phenophase (2012 and 2013) and pentad temperature (daily mean air temperature for 5 consecutive days of 1961–2011). During the fast growth stage (DOY 97–199), defined as the time between the first pentad temperature for 10 °C and the first peak aboveground biomass, the aboveground biomass increased rapidly during this stage. During the middle growth stage (DOY 200–260), defined as the stage from the first peak aboveground biomass to the second peak aboveground biomass, vegetation posted slower growth for booting and heading during this stage. During the terminal growth stage (DOY 261–311), representing the time from the second peak aboveground biomass to the first pentad temperature for 10 °C, the community senesced during this stage.

2.2. Eddy covariance and meteorological measurements

Eddy covariance and microclimate measurements were conducted at the site during 2012 and 2013. Ecosystem CO_2 fluxes were measured using an EC system mounted 3.0 m above the soil surface. The densities of CO_2 and H_2O were measured by an open-path infrared gas analyzer (IRGA, LI-7500, LI-COR Inc., USA), and the three wind components and the speed of sound were measured with a three-axis sonic anemometer (CSAT-3, Campbell Scientific Inc., USA). Raw data outputs from the

IRGA and sonic anemometer were collected at 10 Hz and recorded by a data logger (CR1000, Campbell Scientific Inc., USA) at 30 min intervals. The IRGA was calibrated once or twice every year in the laboratory using pure nitrogen gas, CO_2 calibration gas, and a dew point generator (LI-610, Li-COR Inc., USA). As the uniform fetch was at least 300 m in all directions, the majority of fluxes came from the target area.

Meteorological parameters were measured with an array of sensors. Net radiation was measured at a height of 3.0 m with a four-component net radiometer (CNR4, Kipp & Zonen Netherlands Inc., Bohemia, NY, USA). Photosynthetic active radiation (PAR) was measured above the canopy at a height of 3.0 m using quantum sensors (LI-190SB, Li-Cor Inc., USA). Air temperature and relative humidity were measured at the height of 2.5 m (HMP45C, Vaisala, Helsinki, Finland). Other environmental variables measured included wind speed and direction (034B, Met One Inc., USA), precipitation (TE525 tipping bucket gauge, Texas Electronics, Texas, USA), soil temperature at 5, 10, 30, and 50 cm depths below the surface (109SS, Campbell Scientific Inc., USA), and SWC at 5, 10, 20, 40, 60, 80, and 100 cm depths below the surface (EnviroSMART SDI-12, Sentek Pty Ltd., Australia). More details about the meteorological measurements are presentated elsewhere (Han et al., 2015). All meteorological data were measured every 15 s and then averaged half hourly by a data logger (CR1000, Campbell Scientific Inc., USA).