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Agricultural reclamation effects on ecosystem CO_2 exchange of a coastal wetland in the Yellow River Delta

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ABSTRACT

Little is known about the impacts of agricultural exploitation of coastal wetlands on ecosystem CO_2 exchange, although coastal wetlands have been widely reclaimed for agricultural use across the world. We measured net ecosystem CO_2 exchange (NEE) and its major components, gross primary production (GPP) and ecosystem respiration (R_{eco}) using an eddy covariance flux technique in a natural coastal wetland (reed) and an adjacent, newly reclaimed farmland (cotton) in the Yellow River Delta, China. The results showed that agricultural reclamation changed the ecosystem CO_2 exchange of the coastal wetland at three distinct levels. Initially, the conversion from the wetland to farmland changed the light response parameters (α, A_{max}, and $R_{eco,\,day}$) of NEE and temperature sensitivity (Q_{10}) of R_{eco} mainly by changing the dominant vegetation type. Over the growing season, NEE, R_{eco} and GPP were significantly correlated with LAI at both sites and aboveground biomass at the farmland site. Next, the reclamation of wetland modified the diurnal and seasonal dynamics of ecosystem CO_2 exchange. Significant differences in diurnal variations of NEE between the wetland and farmland sites were found during the growing season (with the exception of June and July). Seasonal means of daily GPP and R_{eco} values at the wetland site were higher than those at the farmland. Ultimately, the agricultural reclamation altered the CO_2 sequestration capacity of the coastal wetland. The cumulative NEE in the wetland ($-237.4\,g\,C\,m^{-2}$) was higher than that in the farmland ($-202.0\,g\,C\,m^{-2}$). When biomass removal was taken into account, the farmland was a strong source for CO_2 of around $131.9\,g\,C\,m^{-2}$ during the growing season. Overall, land use changes by reclamation altered ecosystem CO_2 exchange at several ecological scales by changing the dominant vegetation type and altering the ecosystem's natural development.

1. Introduction

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 (Choi and Wang, 2004; Laffoley and Grimsditch, 2009; Crooks et al., 2011). Globally, at least 430 Tg of C is stored in the upper 50 cm of tidal salt marsh soils (Chmura et al., 2003). Coastal wetlands accumulate organic matter because of their relatively high net primary productivity (NPP) coupled with a relatively low rate of decomposition of accumulated organic matter (Vicari et al., 2011; Crooks et al., 2011; Hu et al., 2012). Furthermore, methane (CH_4) emissions are much lower from coastal wetlands compared to freshwater wetlands, mainly because the relatively high inputs of sulfate from marine waters promote sulfate reduction and hinders CH_4 production (Poffenbarger et al., 2011; Callaway et al., 2012). Therefore, coastal wetlands could be more valuable C sinks per unit area than other ecosystems because of their higher rates of C sequestration and lower CH_4 emissions (Choi and Wang, 2004; Crooks et al., 2011).

Unfortunately, coastal wetlands are reclaimed for agriculture in many parts of the world (Hassan et al., 2005; Laffoley and Grimsditch, 2009; Crooks et al., 2011). An estimate shows that about 50% of the global wetlands have been exploited for agricultural and other land uses (Verhoeven and Setter, 2010). In China, more than half (approximately $7082.0\,km^2$) of salt marshes have been reclaimed for other land uses, which exceeds the area of China's marshes today (Yang and Chen, 1995). Various studies have shown that reclamation of wetlands for agricultural or other land uses not only halts ongoing C sequestration but releases soil C stores (e.g. Santín et al., 2009; Wang et al., 2010; Crooks et al., 2011). On one hand, reclamation can have a large impact on wetland hydrology, which consequently changes the temperature and anaerobic

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conditions in wetlands, leading to emissions of greenhouse gases. On the other hand, when the soil layer of wetlands is reclaimed and oxygen enters soils, large amounts of C are released into the atmosphere in the form of CO_2 (Crooks et al., 2011). Moreover, wetland reclamation can influence the quality of soil organic matter through changes in the plant community composition, productivity, or belowground allocation in wetlands (Keller et al., 2004). Thus, it is important to quantify the changes in C cycles caused by the conversion from wetland to farmland. However, little information is available on the effects of reclamation on C budgets in coastal wetlands at ecosystem or regional scales.

As a typical coastal wetland, the Yellow River Delta is one of the most active regions of land–ocean interaction in the world. In most of the area, groundwater levels range from 1 to 3 m, with high water salinity (5–30 g L^{-1}) (Yang et al., 2009; Fan et al., 2011). Driven by strong evaporation, soluble salt in the shallow water table is transported upward to the root zone and soil surface through capillary rise (Yao and Yang, 2010; Zhang et al., 2011). Consequently, the Yellow River Delta is naturally characterized by extensive coverage of saline soils, which accounts for 47–70% of the land area of the Yellow River Delta (Xie et al., 2011). Opposing these effects, the freshwater inflow from river runoff and net precipitation can leach salts from the plant root zone in coastal wetlands. Therefore, under the combined action between freshwater and seawater, as well as between groundwater and surface water, the vegetation in the coastal wetland exhibits a patchy distribution, and the natural vegetation is composed of aquatic and halophytic plant communities, dominated by herb and shrub species (Fan et al., 2011; Xie et al., 2011; Zhang et al., 2011).

Meanwhile, as a significant agricultural production base, the Yellow River Delta has been undergoing extensive and rapid development of agriculture over recent decades (Zhang et al., 2011; Huang et al., 2012). Since 1981, farmers have been cultivating cotton and maize in fields with low salinity (Yao and Yang, 2010), and a large portion of coastal wetlands have been converted to dry lands for salt-tolerant crops in recent years (Huang et al., 2012). For example, over the past 20 years natural wetlands land cover has decreased by 38.6% from 2566 km^2 in 1986 to 1575 km^2 in 2008 (Wang et al., 2012). Among these natural wetlands, the marsh wetland was reduced by 65.09 km^2 during the period from 1986 to 2005 (Huang et al., 2012). As previously described, at both regional and global scales, wetland conversion to agricultural lands has a great effect on C cycles, especially net ecosystem CO_2 exchange (NEE). Studies have also been undertaken concerning changes of soil C content in reclaimed wetlands in the Yellow River Delta (e.g. Yang et al., 2009; Huang et al., 2012; Yu et al., 2012). However, to date few studies have focused on the effects of reclamation effect on NEE and its controlling factors in coastal wetlands.

The eddy covariance (EC) technique is the most widespread and commonly used method for the spatial integration of CO_2 fluxes at landscape scales and is also applied to measure the CO_2 exchange between terrestrial ecosystems and the atmosphere. Therefore, the EC methods can improve our understanding of the impact of reclamation on ecosystem scale C budgets, since it can provide continuous, long-term flux information integrated at the ecosystem scale (Baldocchi, 2003). In this study, we set up paired EC flux towers to measure NEE in two adjacent ecosystems, a natural coastal wetland (reed) and a newly reclaimed farmland (cotton) in the Yellow River Delta, China. The objectives of this study were (1) to determine the diurnal and seasonal variation of ecosystem CO_2 exchange and calculate the C balance during the growing season for a wetland and a neighboring farmland; (2) to quantify and compare the ecosystem CO_2 exchange of the two ecosystems response to meteorological conditions and phenological development; (3) to investigate the impact of reclamation of a natural wetland on ecosystem CO_2 sequestration.

2. Materials and methods

2.1. Site description

The study was conducted in Yellow River Delta Ecological Research Station of Coastal Wetland (37°45′50″N, 118°59′24″E), Chinese Academy of Sciences. The experimental site has a warm-temperate and continental monsoon climate with distinctive seasons. The annual mean temperature is 12.9 °C, with minimum and maximum mean daily temperatures of −2.8 °C in January and 26.7 °C in July, respectively. The average annual precipitation is 550–640 mm, with nearly 70% of the precipitation falling between May and September. The prevailing wind direction in the growing season is from the northeast to the southeast (Han et al., 2013). Soil type in the Yellow River Delta gradually varies from fluvo-aquic to 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. The natural vegetation in this area consists of salt tolerant herbs, grasses, and shrubs. The gradually increasing groundwater table and salinity from inland to the coast result in a vegetation gradient from aquatic to halophytic communities (Fan et al., 2011).

Based on the current and historic land use, two study sites, a natural coastal wetland and a recently reclaimed farmland were chosen within the study area. The distance between the two towers is 800 m. The terrain at the two sites is flat with a sufficient fetch to meet the basic assumption for proper application of the EC technique. The coastal wetland ecosystem was dominated by *Phragmites communis*, *Suaeda heteroptera*, *Apocyman venetum*, *Sonchus brachyotus* and *Tamarix chinensis* community. During our study, its canopy was 0.3–1.7 m high, with the canopy closure index ranging from 0.3 to 0.8. The growing season of the coastal wetland ecosystem spans from May to October. During the rainy season (mid-July to mid-August), surface ponding (often less than 5 cm) was often observed in the coastal wetlands for time periods of less than 10 days (Han et al., 2013). The farmland, which was reclaimed in April 2008, was used for planting of cotton (*Gossypium hirsutum* L.). Cotton was planted in early May at a moderate density (5.3 plants m^{-2}) and harvested at the end of October in the Yellow River Delta. After sowing, soils were mulched with transparent plastic film (0.008 mm) along the rows, which can reduce salt accumulation and moisture loss in the soils. The maximum canopy height at the peak of the growing season (early July to mid-August) reached up to 1.50 m. After cotton was picked, the cotton plants including roots were harvested and taken away from the fields in order to control pests and diseases or to be burned as domestic fuel. The soil physical and chemical properties in the natural wetland and the reclaimed farmland are presented in Table 1.

2.2. Eddy covariance and meteorological measurements

Eddy covariance and microclimate measurements were conducted at both research sites during the 2011 growing season (May–October). More details about the monitoring system are presented elsewhere (Han et al., 2013). Ecosystem CO_2 fluxes were measured using a paired EC system mounted 3.0 and 2.8 m above the soil surface for the coastal wetland and farmland ecosystems, respectively. The EC system included a three-axis sonic anemometer (CSAT-3, Campbell Scientific Inc., USA) and open path infrared gas analyzer (IRGA, LI-7500, Li-COR Inc., USA). Calculations with a footprint model (Hsieh et al., 2000) indicated that approximately 86% and 70% of the cumulative flux footprint originated within