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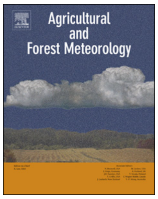

Precipitation events reduce soil respiration in a coastal wetland based on four-year continuous field measurements

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ABSTRACT

Coastal wetlands are considered as a significant sink for global carbon because their organic-rich soils. Given exposed to shallow water tables, water from groundwater is transported upward to the root zone through capillary rise, thus soil moisture in coastal wetlands is relatively high even when there is no precipitation. We expected that as precipitation occurred, the soils in coastal wetlands might become quickly saturated and lead to the development of anoxic conditions. We further hypothesized that such anoxic conditions might decrease soil respiration by limiting oxygen availability and biological activities of roots and microorganisms. Based on continuous automated soil respiration data collected in a coastal wetland in the Yellow River Delta over 4 years (2012–2015), the results showed that on the annual scale, cumulative soil respiration was 317, 321, 231, and 274 $g\,C\,m^{-2}\,yr^{-1}$ for 2012, 2013, 2014, and 2015, respectively, with an average of 286 $g\,C\,m^{-2}\,yr^{-1}$. The rate of soil respiration increased exponentially with soil temperature during each year and its two seasons (growing season and non-growing season). In addition, soil respiration was significantly related to soil moisture during the growing season, but was not affected by soil moisture during the non-growing season. After each precipitation event, soil respiration was significantly negatively correlated with soil moisture under different initial soil water contents. There was a significant positive correlation between changes in soil respiration and changes in soil moisture following precipitation events. Moreover, the increase of soil moisture following precipitation events changed the temperature response of soil respiration. Our study indicated that precipitation events could decrease soil respiration by increasing soil moisture and inducing anoxic conditions in the coastal wetland. Therefore, we speculate that the continuation of decreasing precipitation and increasing temperature trends in the Yellow River Delta may increase soil carbon losses in the coastal wetland due to the increase in soil respiration.

1. Introduction

Changes in precipitation event size or frequency can alter soil moisture to influence soil respiration in a variety of ecosystems (Batson et al., 2015; Vidon et al., 2016). However, the effects of precipitation events on soil respiration are variable and ecosystem-dependent, and have no definite conclusion (Jiang et al., 2013; Zhang et al., 2015). Numerous previous studies have addressed that soil respiration typically quickly increases following precipitation events after periods of dryness (often called “Birch effect”), especially in arid and semi-arid regions (McIntyre et al., 2009; Bowling et al., 2011; Yan et al., 2014; Rey et al., 2017). The enhancement of CO_2 release can constitute a substantial portion of annual soil respiration (Wu and Lee, 2011; Waring and Powers, 2016), which might have potential important consequences for soil carbon (C) stocks (Wang et al., 2015; Rey et al., 2017). However, opposing results indicated that soil respiration was depressed by precipitation events in temperate and subtropical forests (Wang et al., 2012; Liu et al., 2014). Similarly, decreasing soil moisture levels by precipitation reduction increased CO_2 fluxes to the atmosphere in tropical rain forests (Cleveland et al., 2010; Zhang et al., 2015). In addition, a recent observation suggested that rainfall could result in absorption of atmospheric CO_2 by soils in a desert (Fa et al., 2015). Given that precipitation events may influence soil respiration with widely varying uncertainty, it is imperative to determine the

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response of soil respiration to precipitation event in order to precisely predict soil C balance.

These contradictory results about precipitation effects on soil respiration may be due to differences in seasonal climate variation and soil conditions, especially initial soil moisture condition (Shi et al., 2011; Wu and Lee, 2011; Yoon et al., 2014; Rey et al., 2017). Under dry soil conditions, increasing soil moisture following precipitation during the transition from dry to wet soil conditions is accompanied by increasing soil respiration (Shi et al., 2011; Liu et al., 2014; Rey et al., 2017), which may be attributable to water-driven increases in microbial biomass and activity, root respiration following enhanced photosynthesis, and degassing of soil pore space CO_2 (Nielsen and Ball, 2015). However, under humid soil conditions, as precipitation occurs, soil becomes saturated or flooded with a subsequent continuous increase in soil moisture, which limits the diffusion of O_2, and reduces microbial activity and CO_2 production (Jimenez et al., 2012; McNicol and Silver, 2014; Vidon et al., 2016). Therefore, the direction and magnitude of the soil respiration induced by precipitation may be controlled by initial soil moisture and precipitation size and frequency. Since relatively modest changes in the quantity or timing of precipitation may have disproportionately large impacts on annual soil respiration (Wang et al., 2015; Waring and Powers, 2016; Rey et al., 2017), accurately quantifying soil respiration response to precipitation events is essential to understand soil C balance dynamics. In addition, considering that globally precipitation patterns have been predicted to change with increasing intra-annual variability and more frequent extremes (IPCC, 2013), rainfall events may become even more important in the near future (Rey et al., 2017).

Coastal wetlands are considered as significant sink for global C and contributors to global “blue carbon” resources (Laffoley and Grimsditch, 2009; Livesley and Andrusiak, 2012), with high primary productivity, a low soil organic matter decomposition rate, a low CH_4 generation rate, and the ability to trap and bury significant amounts of allochthonus C (Mcleod et al., 2011; Poffenbarger et al., 2011; Hopkinson et al., 2012). Globally, the organic-rich soils of many coastal wetlands contain exceptionally large C stocks, which can be two to three times higher than those in most terrestrial ecosystems (Chmura et al., 2003; Donato et al., 2011; Livesley and Andrusiak, 2012). Thus the soil C stocks in the coastal soils have been received much interest because the minor change of C pool will have a remarkable impact on the global C cycle (Chambers et al., 2013). Due to low elevation and proximity to the ocean, shallow groundwater may be present in many coastal wetlands under different geologic settings (Hoover et al., 2016). Therefore, the surface soils in coastal wetlands may experience large fluctuations between fresh-water and seawater, as well as between groundwater and surface water, which have the potential to significantly alter the C mineralization rate, microbial activity and nutrient dynamics (Cui et al., 2009; Fan et al., 2012; Han et al., 2014). Except of tidal wetlands, the most area of coastal wetlands are lie beyond the reach of the tides, where the hydrologic regimes are dominated by the interaction of precipitation, saline water tables, and marine sediments (Zhang et al., 2011; Han et al., 2015). The hydraulic connection between soil water and groundwater directly influences the water and salt conditions in the soil (Xie and Yang, 2013). When the water table and capillary fringe are close to the soil surface, then only small amounts of applied water are necessary to saturate the soil profile completely (Sophocleous, 2002). Because water and water-soluble salts from the groundwater are transported upward to the root zone through capillary rise and evaporation (Zhang et al., 2011; Han et al., 2015), soil moisture in coastal wetlands is relatively high even when there is no precipitation. In addition, saturated soils including flooded or ponded soils are often observed following rainfall events (Han et al., 2015). Therefore, the soils in coastal wetlands exposed to shallow groundwater are sensitive to precipitation events and might easily induce changes between aerobic and anaerobic status, which can regulate soil respiration. Thus, accurately quantifying response of soil respiration to precipitation events is essential to understand C balance dynamics in these belowground dominated ecosystems (Rey et al., 2017).

Unfortunately, relatively few long-term (multi-year) studies of soil respiration covering periods of interannual variability in seasonal weather are available from coastal wetlands. Therefore, it is unclear how the soil respiration responses to precipitation events and associated changes in moisture conditions in these regions. The development of automated soil respiration measurements with high temporal resolution under natural conditions provides an excellent opportunity to examine and evaluate soil respiration response to precipitation evens. We expected that as precipitation occurred in coastal wetlands, the soils might become quickly saturated for several days due to shallow water tables, which leaded to the development of anoxic conditions. We further hypothesized that such anoxic conditions might decrease soil respiration by limiting oxygen availability, and hence the increasing in soil moisture due to increasing precipitation could protect soil C by decreasing soil respiration. Based on continuous automated soil respiration data collected in a coastal wetland in the Yellow River Delta over 4 years (2012–2015), our objectives are (1) to characterize seasonal and interannual variations of soil respiration of the ecosystem, (2) to quantify the main environmental drivers behind the seasonal variations of soil respiration, (3) to identify the response patterns and magnitudes of rain-induced soil respiration, and (4) to gain new insights into the underlying mechanisms responsible for the changes in soil respiration following precipitation events.

2. Materials and methods

2.1. Site description

The Yellow River Delta, one of the most active regions of land-ocean interaction in the world, is located in the southern bank of the Bohai Sea and the western Laizhou Bay. The Yellow River has changed its course more than ten times since 1855, and created more than 2500 km^2 of new wetlands. Due to the low elevation (generally below 10 m) and being near the sea, the hydrological characteristics in the Yellow River Delta are affected by the interactions between freshwater and seawater and between groundwater and surface water (Cui et al., 2009). The groundwater table in this region is shallow with an average depth of 1.1 m (Fan et al., 2012), with a high level of ground-water mineralization averaging 30.1 $g\,L^{-1}$ (Yang et al., 2009), which are mainly influenced by the tidal process and the Yellow River runoff (Luan and Deng, 2013).

It has a warm-temperate and continental monsoon climate with distinctive seasons and rainy summer. The annual average 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 560 mm, and nearly 70% of the annual precipitation is concentrated in the period of July to September. Thus, surface flooding is often observed in this region, especially following heavy rainfall events. During dry season (April–June), driven by strong evaporation, water and soluble salt in the shallow water table are transported upward to the root zone, therefore the surface soil moisture and salinity are relatively high. Generally, the soil type of coastal wetlands in the Yellow River Delta gradually varies from fluvo-aquic to saline soil, and the soil texture is mainly sandy clay loam (Nie et al., 2009).

The study sites are located at the Research Station of Coastal Wetland in the Yellow River Delta (37° 45′ 50″N, 118° 59′ 24″E), Chinese Academy of Sciences, in Kenli County, Shandong Province, China. In our research sites, the vegetation is relatively homogeneous and strongly dominated by common reed (*Phragmites australis*), with other associated species including *Suaeda salsa*, *Tamarix chinensis*, *Imperata cylindrical,* and *Tripolium vulgare*. The maximum canopy height at the peak of the growing season (early July to mid-August) can reach up to 1.7 m, and the closure index was between 0.3 and 0.8 (Han et al., 2015). The growing season of the coastal wetland ecosystem spans from