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Salinity and nutrient contents of tidal water affects soil respiration and carbon sequestration of high and low tidal flats of Jiuduansha wetlands in different ways

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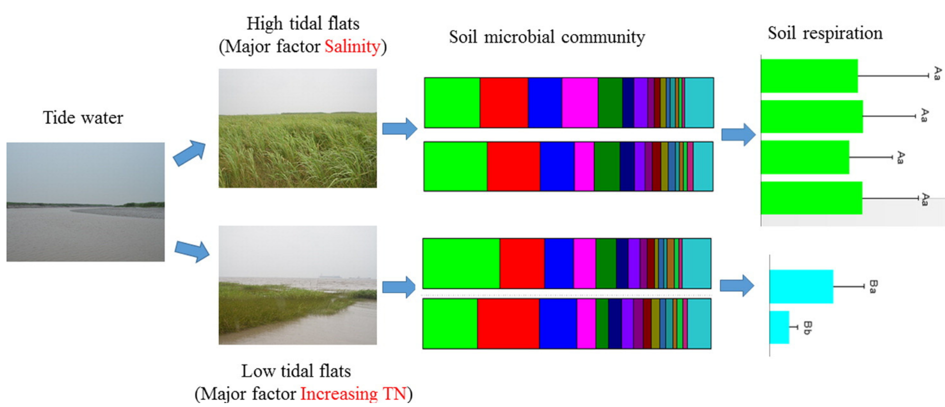
HIGHLIGHTS

- Effect of tidal salinity and nutrient levels on SR in estuarine wetlands was studied.
- Tidal water affects microbial property and SR of low and high tidal flat differently.
- TN input was the main factor affecting microbial properties and SR in low tidal flat.
- Salinity was the main factor affecting microbial properties and SR in high tidal flat.
- High soil autotrophic activity contributed to relatively low SR in high tidal flat.

GRAPHICAL ABSTRACT



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ABSTRACT

Soils were collected from low tidal flats and high tidal flats of Shang shoal located upstream and Xia shoal located downstream with different tidal water qualities, in the Jiuduansha wetland of the Yangtze River estuary. Soil respiration (SR) in situ and soil abiotic and microbial characteristics were studied to clarify the respective differences in the effects of tidal water salinity and nutrient levels on SR and soil carbon sequestration in low and high tidal flats. In low tidal flats, higher total nitrogen (TN) and lower salinity in the tidal water of Shang shoal resulted in higher TN and lower salinity in its soils compared with Xia shoal. These would benefit β-Proteobacteria and Anaerolineae in Shang shoal soil, which might have higher heterotrophic microbial activities and thus soil microbial respiration and SR. In low tidal flats, where soil moisture was high and the major carbon input was active organic carbon from tidal water, increasing TN was a more important factor than salinity and obviously enhanced soil microbial heterotrophic activities, soil microbial respiration and SR. While, in high tidal flats, higher salinity in Xia shoal due to higher salinity in tidal water compared with Shang shoal benefited γ-Proteobacteria which might enhance autotrophic microbial activity, and was detrimental to β-Proteobacteria in Xia shoal soil. These

Abbreviations: SOC, soil organic carbon; SR, soil respiration; SMR, soil microbial respiration; SMB, soil microbial biomass; HTFs, high tidal flats; LTFs, low tidal flats.

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might have led to lower soil microbial respiration and thus SR in Xia shoal compared with Shang shoal. In high tidal flats, where soil moisture was relatively lower and the major carbon input was plant biomass that was difficult to degrade, soil salinity was the major factor restraining microbial activities, soil microbial respiration and SR.

1. Introduction

The soil organic carbon (SOC) pool, which has a dynamic exchange with the atmospheric carbon pool, plays an important role in the global carbon cycle. Even small changes in SOC stocks can lead to major impacts on atmospheric carbon dioxide (CO_2) concentrations (Lal, 2008; Nielsen et al., 2011; Stockmann et al., 2013). Soil respiration (SR) is the primary mechanism through which soil carbon is released to the atmosphere (Davidson et al., 2006; Kuzyakov and Larionova, 2005). Any increases in SR in response to environmental changes may exacerbate increasing atmospheric CO_2 levels and result in positive feedback to global warming (Jenkinson et al., 1991; Kirschbaum, 1995; Schulze, 2006). SR has two major components: (1) plant root respiration, which includes the rhizomicrobial respiration; and (2) respiration of microorganisms living in the soil (Gomez-Casanovas et al., 2012). Therefore microorganisms play a significant role in carbon exchange between soil and atmosphere (Singh et al., 2010), and variations in soil community composition and microbial activity may affect SR and subsequent soil carbon loss (Allison et al., 2010; Carney et al., 2007).

Wetlands are normally considered to be natural carbon sinks due to being highly productive ecosystems with low rates of organic carbon decomposition, as a consequence of their frequent flooded conditions (Bernal and Mitsch, 2012). Despite covering only 4–6% of the earth's land surface (Mitsch and Gosselink, 2007; Sharitz et al., 2014), the SOC pool of wetlands is estimated to be about one-third of the total SOC pool (Mitsch and Gosselink, 2007). Consequently, wetlands are of great significance in the global carbon cycle and many previous studies have focused on interior wetlands, especially boreal peatlands (Belyea and Malmer, 2004; Euliss et al., 2006; Fleischer et al., 2016). However, with global warming, increasing attention has been paid to carbon sequestration in coastal and estuarine wetlands over the past 20 years (Chen et al., 2015; Drake et al., 2015; Kirwan and Mudd, 2012).

Estuarine wetlands are unique, being ecosystems where the land connects to the sea and fresh meets salt water. They are also defined as ecotones between river and marine ecosystems (Cowardin et al., 1979). Therefore, salinity often has an obvious gradient along estuarine wetlands. Despite their many important ecological functions, such as coastal protection, water quality purification, being important habitats for many beneficial species and especially strong capacity for carbon sequestration (Chmura et al., 2003; Davy et al., 2009; King and Lester, 1995; Morgan et al., 2009), estuarine wetlands are greatly threatened by human activities as estuarine areas are generally economically developed (Barbier et al., 2011). Current threats to estuarine wetlands mainly include sea-level rise, pollution and eutrophication (Silliman et al., 2009).

The soil properties of estuarine wetlands are easily affected by tidal water properties, resulting in impacts on their ecological functions. Hu et al. (2014) reported that salinity restrained the SR of estuarine wetland in the Yangtze River estuary through changing the soil physicochemical and microbial properties. Zhang et al. (2015) indicated that water organic pollution and eutrophication would promote the soil microbial activities and SR in low tidal flats (LTFs) of an estuarine wetland in the Yangtze River estuary. However, the periods of waterlogging for high tidal flats (HTFs) and LTFs in estuarine wetlands are quite different, and thus the effects of tidal water on the wetland soils should also differ. Differences in how salinity and nutrient contents of tidal water affect soil properties as well as SR and if their proportionate influences vary between HTFs and LTFs have not been reported in detail. One possible reason for this lack of information might be the difficulty in finding a suitable estuarine wetland with similar vegetation and approximate vegetation biomass, as well as soil texture in both HTFs and LTFs, respectively, but with varied tidal water salinity and nutrient levels. However, understanding the different effects of tidal water salinity and nutrient levels on soil microbial properties and SR in LTFs and HTFs of estuarine wetlands and determining their proportionate influences is of great significance for understanding the potential effects of sea-level rise, aggravated by organic pollution and eutrophication, on estuarine wetlands as related to soil carbon sequestration.

The Jiuduansha wetland is the sole original ecological tidal wetland ecosystem in the Yangtze River estuary and an important nature reserve in Shanghai, spanning about 40 km from the Yangtze River in the west to the East China Sea in the east (Tang et al., 2011). The wetland also faces the threat of water pollution like many other estuarine wetlands – particularly drain outlets of some large sewage plants are placed upstream of the Jiuduansha wetland. Consequently, the salinity and nutrient contents of tidal water in the Jiuduansha wetland vary greatly from upstream to downstream and made this wetland a suitable site for investigating the effects of tide salinity and nutrient levels on soil abiotic and microbial properties in HTFs and LTFs. Previous studies reported how the salinity and nutrient levels of tidal water respectively influenced the soil microbial properties and SR of the Jiuduansha wetland in LTFs (Xi et al., 2014; Zhang et al., 2015). However, the soil environment could be quite different between HTFs and LTFs due to the variations in waterlogging time and the properties of the carbon input from litter into the soils. We hypothesized that salt and nutrients such as nitrogen and phosphorus from tidal input would affect the soil microbial properties, as well as SR, differently between LTFs and HTFs in Jiuduansha wetlands. We further hypothesized that the major factor influencing the carbon turnover between LTFs and HTFs in Jiuduansha wetlands would vary due to their different impacts on the soil microbial community.

The overall objective of the current work was to describe the influence of increasing salinity and nutrient levels of the tidal water on soil physiochemical and microbial properties and its effects on carbon turnover in LTFs and HTFs of Jiuduansha wetlands, and to compare the differences of the proportionate influences of salinity and nutrient levels between HTFs and LTFs. The results will provide new insight into how sea-level rise combined with organic pollution and eutrophication aggravation will affect the soil carbon turnover of estuarine wetlands.

2. Materials and methods

2.1. Site description

The Jiuduansha wetland (31°03′–31°17′ N, 121°46′–122°15′ E) located in the Yangtze River estuary, covers about 423.2 km^2 and is composed of the following three shoals: Shang, Zhong and Xia shoals. The wetland initially emerged above the water surface in the 1920s and rapidly became an independent wetland in the 1960s. After a half-century of dynamic evolution, the Jiuduansha wetland has become more or less stable. The Jiuduansha wetland is an original landform wetland and was designated as the Jiuduansha National Wetland Nature Reserve in 2005 (Tang et al., 2011). It has an East Asia subtropical monsoon climate with an average annual temperature of 17.3 °C. The mean annual precipitation is approximately 1200 mm. The highest elevation of the wetland was up to 4 m in 2004 (Li et al., 2016). The average and maximum tidal ranges are 2.67 and 4.62 m, respectively (Huang and Zhang,