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Plant litter composition selects different soil microbial structures and in turn drives different litter decomposition pattern and soil carbon sequestration capability

Jianfang Yan[a,b], Lei Wang[a,b,*], Yu Hu[a,b], Yiu Fai Tsang[c], Yannan Zhang[a,b], Jihua Wu[d], Xiaohua Fu[a,b], Ying Sun[e]

[a] Key Laboratory of Yangtze River Water Environment, Ministry of Education, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China
[b] Shanghai Institute of Pollution Control and Ecological Security, China
[c] Department of Science and Environmental Studies, The Education University of Hong Kong, Hong Kong, China
[d] Ministry of Education, Key Laboratory for Biodiversity Science and Ecological Engineering, School of Life Science, Fudan University, Shanghai 200433, China
[e] Shanghai Jiuduansha Wetland Nature Reserve Administration, Shanghai 200135, China

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ABSTRACT

Few studies have explored the successive impacts of plant litter composition on soil microbial structure and function, litter decomposition patterns and final soil carbon sequestration. In this study, two dominant halophytes in the Jiuduansha Wetland of the Yangtze River estuary, *Phragmites communis* and *Spartina alterniflora*, were selected for in-situ and ex-situ decomposition experiments aiming to clarify the difference in decomposition rate of their litter types in soil. Furthermore, plant litter composition, soil organic carbon and humus contents, soil respiration, microbial respiration and soil microbial structure were analyzed to explore dominant decomposition patterns of the two types of litter in soil and their organic carbon sequestration capability, as well as the microbiological mechanisms involved. The *S. alterniflora* litter decomposed faster in soil than *P. communis* due to its lower contents of cellulose and lignin. More degradable carbon in *S. alterniflora* litter induced higher proportions of the microbial community responsible for mineralization in the soil, such as classes β-Proteobacteria and γ-Proteobacteria and genera *Geobacter* and *Flavobacterium*, leading to higher soil respiration. Consequently, despite the *S. alterniflora* zone having higher aboveground plant biomass than the *P. communis* zone, there were lower contents of soil organic carbon and humus. The *P. communis* zone, in contrast, on account of the induced higher proportion of a specific microbial community, such as class Anaerolineae and genera *Methylibium*, *Gallionella* and *Desulfococcus* – which potentially weakened mineralization and accelerated humification – resulted in lower soil respiration and thus higher contents of soil organic carbon and humus. These indicated that plant biomass was not the only factor affecting the soil organic carbon content; plant litter composition was also an important factor because it induced different soil microbial community structures which led to different organic carbon decomposition patterns, and therefore different soil organic carbon sequestration capability.

1. Introduction

Plants are carbon pumps for ecosystems and they maintain carbon cycling in a dynamic balance between soil and atmosphere (Martins and Angers, 2015; White et al., 2010). Plants fix carbon dioxide (CO_2) from the atmosphere through photosynthesis, then transfer the fixed organic carbon to the soil through plant litter and root exudates. The organic carbon in plant litter can be further decomposed and converted in soil, mainly by humification and mineralization, both of which are driven by microorganisms (Berg and McClaugherty, 2014). During the former process, plant litter is first converted to intermediate products of carbohydrate, organic phosphorus compounds and nitrogenous organic compounds, and then condensed to stable humic substrates (Lähdesmäki and Piispanen, 1988). This is the main way that soil organic carbon (SOC) is formed. In the mineralization process, organic carbon in litter is gradually transformed into simpler substrates and ultimately to CO_2 which is manifest as soil respiration (SR) (Prescott, 2010). This is the main pathway for the recycling of organic carbon

* Corresponding author at: Key Laboratory of Yangtze River Water Environment, Ministry of Education, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China.
E-mail address: celwang@tongji.edu.cn (L. Wang).

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from plant litter to the atmosphere.

Plants with greater biomass and faster growth have more organic carbon returning to the soil every year, so that the soil ecosystem may sequester more organic carbon (Cheng et al., 2006). Such plants are traditionally considered as high carbon-sequestration plants for soil. If plants with greater biomass were subject to a much higher level of mineralization when litter returned to soil, then more carbon would be released back to the atmosphere and less organic carbon retained in soil. Consequently, litter decomposition rates and patterns are other important factors determining soil carbon sequestration in addition to plant biomass.

There have been many studies on the relationship between litter properties and their decomposition rates in soil, and the effects of litter composition on soil microbial structure have also been reported (Berg and McClaugherty, 2014; Giudice and Lindo, 2017; Zhou et al., 2015). The properties of plant litter affect its decomposition in soil in both early stage and late stage decomposition (Giudice and Lindo, 2017). Berg and McClaugherty (2014) demonstrated that plant litter provides the substrate for soil microorganisms, and thereby significantly influences microbial community structure through the availability of nutrients and the unique soil microenvironment created by its different chemical components. However, several questions remain, such as the extent to which the properties of litter influence mineralization or humification in soil, and how different decomposition patterns (such as mineralization or humification) affect sequestration of litter carbon in soils. To what extent are the different decomposition patterns of litter types determined by the structure of the soil microbial communities that are induced by different litter types? Do plants with higher biomass definitely produce higher SOC? Such questions have not been studied systematically.

Estuarine wetlands act as important carbon sinks and they are vulnerable to various influences including nutrient input, sea level rise and invasion of alien species (Delaune and White, 2012; Kirwan and Megonigal, 2013). The Jiuduansha Wetland is one of the most representative wetlands in the Yangtze River estuary, China. To date, this place is uninhabited and free from the influence of reclamation and farming, but it is threatened by invasive non-native species. It was reported that invasive *Spartina alterniflora* profoundly changed the carbon turnover of wetland soil (Cheng et al., 2007; Liao et al., 2007; Zhang et al., 2010). *S. alterniflora* is generally documented as a plant with a higher biomass than native *Phragmites communis*, and it was assumed to be beneficial to soil carbon sequestration (Cheng et al., 2006). However, Tang et al. (2011) found that when considering both plant biomass and soil microbial respiration (SMR), per unit mass of *S. alterniflora* led to less organic carbon accumulation in soil than *P. communis*. It is still debatable whether *S. alterniflora* with its high biomass is a true high carbon-sequestration plant for soil compared with *P. communis* in Jiuduansha Wetland. There is no convincing explanation for the lower SOC content under *S. alterniflora*.

Plant litter decomposition in soil is related to its quality, and the humification and mineralization activities of soil directly affect soil carbon turnover (Giudice and Lindo, 2017). We speculated that differences in plant litter composition between *S. alterniflora* and *P. communis* may ultimately affect the decomposition rate and dominant decomposition pattern (i.e. humification or mineralization), and thus soil carbon sequestration. But is it related to the different microbial structures induced by different litter types?

In the present study, in-situ and ex-situ decomposition experiments of *S. alterniflora* and *P. communis* litter were designed to investigate the influence of plant litter quality on the decomposition rate and patterns (i.e. humification or mineralization), and thus organic carbon sequestration. In-situ decomposition experiments were conducted to simulate the natural decomposition processes of the two plant litter types locally. The ex-situ decomposition experiments excluded subtle differences in soil quality between the *S. alterniflora* and *P. communis* zones, which may affect the decomposition process of litter, enabling investigation of only the effects of litter properties on decomposition rate. During the experiment, soil physical–chemical qualities, plant litter properties, SR and soil microbial activities were tested to clearly determine the factors controlling litter decomposition rate and modes, as well as their relationships to soil carbon sequestration. In addition, effects of plant litter on soil microbial biomass (SMB) and microbial community structure were analyzed to further elaborate the microbial mechanisms leading to differences in decomposition patterns.

The experimental results will provide some new knowledge on the relationship between plant biomass, plant quality and soil carbon sequestration and its mechanism – showing what a true high carbon-sequestration plant for soil is.

2. Materials and methods

2.1. Site description

Jiuduansha is the youngest wetland in the Yangtze River estuary. It was formed by Yangtze River sediment under the impact of tide jacking and sedimentation. After dynamic evolution over a century, this island now tends to be stable. At present, Jiuduansha Wetland mainly consists of two shoals from west to east: Shangsha and Zhongxiasha. The total area of vegetation in Jiuduansha Wetland is 56 km^2. The three main vegetation types of *P. communis*, *S. alterniflora* and *Scirpus mariqueter* cover 2213, 2278 and 1089 ha, respectively (Liu, 2013). Among these, *P. communis* is a native species, mostly distributed in medium–high tidal flats of Shangsha and Zhongxiasha; *S. alterniflora* is invasive, mainly distributed in medium–low tidal flats of Zhongxiasha; and *Scirpus mariqueter* is the pioneer plant of Jiuduansha, distributed in low tidal flats (Liu, 2013).

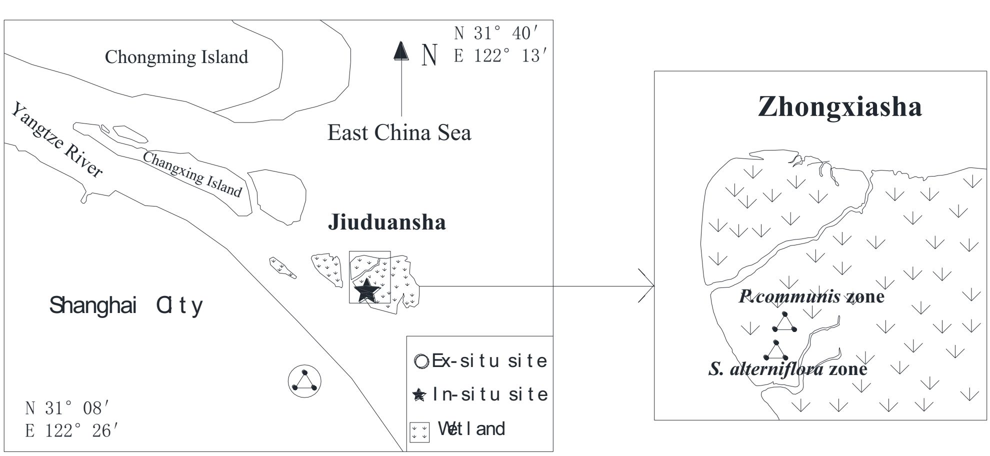

Fig. 1. Map of study areas in Jiuduansha Wetland and plant sampling points.