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Effect of salinity on the decomposition of soil organic carbon in a tidal wetland

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Abstract

Purpose Climate warming and sea level rise have the potential to change the salt level of soil in tidal wetlands. And it is important to clarify the process and the mechanism of decomposition of soil organic carbon in a tidal wetland under varying salinities. The aim of this study was to evaluate the impacts of soil salinity on the decomposition rate of organic carbon (DROC) and dissolved organic carbon (DOC) in a tidal wetland.

Materials and methods Two types of soil (surface soil in Suaeda salsa and bare tidal flat) were collected, air-dried, and homogenized. After adding different content of salt (0 g/L, 3 g/L, 6 g/L, 9 g/L, and 12 g/L), the soils were incubated for 28 days at stable room temperature (25 ± 2 °C) and added by deionized water to maintain the stability of soil moisture. The gases (CO_2 and CH_4) emission rates of each salt treatment were measured during 28-day incubation. DROC was determined by the sum of daily CO_2-C emission rates and daily CH_4-C emission rates in this study.

Results and discussion Salt addition inhibited the process of gas emissions and DROC. Gases emission rates and DROC of two types of soil showed similar temporal trends, with distinctive drop in the beginning of experiment and no significant decrease followed. Significant difference of DOC among salt treatments was found in the bare tidal flat soil. Variations of partial correlation between DROC and soil salinity and DOC showed similar trends (e.g., in days 9–18, the positive effect of DOC on DROC was greatly promoted ($R^2 = 0.80$, $p < 0.001$), and the negative effect of soil salinity was highly improved ($R^2 = 0.93$, $p < 0.001$)). Soil properties, in particular DOC, may be primary factors accounting for the discrepancy of gases emission rates and DROC of two types of soil.

Conclusions Increased soil salinity had a negative effect on DROC during 28-day incubation. The impact of soil salinity and DOC on DROC were varied in different phases of laboratory experiment (soil salinity generally had increasingly negative relationship with DROC, but DOC showed most significantly positive relationship in the middle stage of incubation). Both the formation and consumption of DOC may be valuable for more detail research regarding to decomposition of soil organic carbon.

Keywords Dissolved organic carbon (DOC) · CH_4 · CO_2 · Salinity · Tidal wetlands

1 Introduction

Coastal tidal wetlands are widely regarded as one of the most important carbon sinks and indicators to climate change, in particular sea level rise (Bonneville et al. 2008; Erwin 2009; Kirwan and Mudd 2012; Han et al. 2015). Carbon stored and sequestered in marine and coastal ecosystems is often termed "Blue Carbon," which plays an important part of the global carbon cycle and the mitigation of climate warming (McLeod et al. 2011, Nellemann et al. 2009). Unlike other types of wetlands, a tidal wetland is submerged and exposed under

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periodic tides, which results in salt accumulation and leaching (Han 2017). Increasing salinity has been proved to be a primary environmental stressor, with the potential to influence the rate of carbon (C) sequestration and the function of blue carbon in tidal wetlands (Sangiorgio et al. 2008, Chambers et al. 2011, Lucas and Carter 2013). Because of the valuable carbon sequestration capacity of tidal wetlands, which are mostly under human- and climate- driven threats, it is imperative that we improve our understanding of how tidal wetlands function as blue carbon, and how they are likely to be affected by future changes (McLeod et al. 2011).

Previous studies have demonstrated that salinization leads to various physical changes in soil. High soil salinity leads to flocculation or dispersion of soil different particles and influences solubility of soil organic matter (SOM) (Wong et al. 2009; Wong et al. 2010; Rath and Rousk 2015). Unlike extensive research has been undertaken to analyze the physicochemical properties of saline soil, especially with regard to soil structure (Valzano et al. 2001; Bramley et al. 2003), the effects of salinity on carbon dynamics and mineralization are not as well investigated or understood (Wong et al. 2009). To better understand the implications of salt water intrusions, as well as predicting the impact of soil salinity on organic carbon decomposition in tidal wetlands, the soil incubation experiment with adding different content of salt can provide reliable investigation and estimation (Chambers et al. 2011; Liu et al. 2017). The primary outcome of increasing salinity on carbon dynamics is a decrease in plant productivity, and accordingly carbon inputs to the soil (Liu et al. 2017). High salinity also caused a decrease in microbial activity and consequently slower decomposition rates of dissolved organic carbon (DOC) (Setia et al. 2013). In addition, salinization can influence both solubility and mobility of DOC and potentially the emission of CO_2 and CH_4 (Ardon et al. 2016). Increasing salinity in coastal saline wetlands may result in lower decomposition rate of organic carbon (DROC) (Baldwin et al. 2006; Marton et al. 2012; Zhao et al. 2017). High salinities are frequently combined with low availability of water, and drought conditions intensify the effects of salinity on microbes, including microbial biomass and microbial activity (Chowdhury et al. 2011; Rath and Rousk 2015). On the other hand, low salt concentrations (< 5 ppt) can significantly affect greenhouse gases (CO_2, CH_4, and N_2O) formation in a 60-day soil incubation experiment of coastal wetland soils (Liu et al. 2017).

As one of the most active regions of land-ocean interaction among the large river deltas in the world, the Yellow River Delta (YRD) has the largest and youngest coastal wetland ecosystem in China (Zhang et al. 2016; Guan et al. 2017). The interaction between fresh surface water, saline ground water, and seawater in the YRD has produced a wide variety of wetland types, plant communities, and ecological functions (Fan et al. 2012; Han et al. 2015; Bai et al. 2017). Previous research have demonstrated the degradation of freshwater wetland, and both biodiversity and soil quality have been threatened by water availability and aggravating salt stress in the YRD (Yu et al. 2014; Guan et al. 2017; Zhao et al. 2018). In tidal area, salinization is a serious land degradation issue, which is anticipated to be more important in the future (Metternicht and Zinck 2003; Wong et al. 2008: Yu et al. 2014; Bai et al. 2015). Furthermore, tidal wetlands and their surrounding areas are increasingly vulnerable to the effects of climate change, including air temperature effects and sea level rise, causing ecosystem services to decline (Osland et al. 2016). Accordingly, the salt level of tidal wetlands is generally alternated by climate warming, sea level rise, and plant invasion (Kirwan and Mudd 2012; Zhang et al. 2018), which may influence the DROC and the function of blue carbon.

Therefore, it is important to clarify the process and the mechanism of decomposition of soil organic carbon in a tidal wetland under varying salinities, which is conducive to accurately estimate the carbon sequestration rates. In order to evaluate the impacts of soil salinity on the decomposition rate of organic carbon and DOC in a tidal wetland, a soil incubation experiment was set up by controlling salinity of two types of soil (SS: Suaeda salsa and BTF: bare tidal flat). This study had the following objectives: (1) to compare the soil properties and DROC among soil samples from different land covers (BTF and SS), (2) to quantify gas emissions (CO_2 and CH_4) and analyze the temporal variations of gas emissions under varying salinities, and (3) to demonstrate the impacts of soil salinity on the DROC and DOC in the incubation experiment.

2 Materials and methods

2.1 Study site and sample collection

This study was conducted with soil samples from a tidal salt marsh wetland on the YRD (37° 36′ N, 118° 57′ E), northeastern Shandong Province, China. The existence of periodical water stress and salt stress is caused by periodical tidal invasion at the field site, leading to salt leaching or concentrating on the surface. Sediments from the Yellow River are the main soil parent materials. It is evident that the climate is the warm semi-humid continental monsoon in this area which is associated with moderate temperature, adequate light over the same period. The seasonal and inter annual differences of precipitation are significant and unevenly distributed. In the tidal wetlands, the dominant species of plants are Suaeda salsa and

Spartina alterniflora, which is an aggressive invasive plant species. In early August 2017, two types of typical covering (Suaeda salsa and bare tidal flat) were divided into quadrats (1 × 1 m). And surface soil sample were collected respectively by stainless steel shovels from soil (0–10 cm depth). After removing the visible plant detritus and any fragments, the samples were packed in soil bags, sealed, and transported back to the laboratory. The maximum water holding capacity of the two types of soils was measured by method of single-ring. From each type of the fresh soil, three samples (100 g) were taken, and then stored in a refrigerator (4 °C) to be measured. Physicochemical properties of original soil with different land covers are shown in Table 1. The remaining soil samples were air-dried and stored at stable room temperature, and sieved to a particle size < 2 mm for homogenization. It is possible that soil drying and homogenization would influence the microbial biomass and microbial activity, but it helps minimize the impact of soil heterogeneity in the experiment.

2.2 Setup of salt-treatment experiments and sampling procedure

For each jar (1000 ml) with 200 g of dry soil, the soil moisture was controlled at 60% of the maximum of field water capacity. Salt water was added into each jar for the first day, and then deionized water was added every 2 days to maintain the stability of soil moisture with constant weight. The five setups with different salt levels are labeled as 0 g/L, 3 g/L, 6 g/L, 9 g/L, and 12 g/L. A total of 145 jars were used (14 jars × 5 treatments × 2 types of soil + 5 blank controls), and the temperature of experiment was stably controlled at 25 ± 2 °C.

The gases (CO_2 and CH_4) emission rates of each treatment were measured on the 1st, 2nd, 3rd, 5th, 7th, 9th, 11th, 13rd, 15th, 17th, 20th, 23rd, 26th, and 28th days. The jars were sealed 24 h by parafilm before gas sampling, and then used a syringe with three-way-valve to collect gas samples. Gas concentration was then measured by gas chromatography with comparison of five standard gases. In addition to the gas sample flasks, three replicates of each treatment of each type of soil were terminated on the 8th, 18th, and 28th days. All of the samples were air dried for the following measurement.

Table 1 Soil properties (mean ± standard deviation, $n = 5$) from two different land covers (BTF: bare tidal flat and SS: Suaeda salsa) in a tidal wetland in the Yellow River Delta

Properties	BTF	SS
Clay (%)	17.36 ± 1.08	21.01 ± 0.33
Silt (%)	79.07 ± 0.93	74.84 ± 0.30
Sand (%)	3.57 ± 0.22	4.15 ± 0.07
TC (μg C g^{-1})	1869.20 ± 35.55	2491.25 ± 50.43
TN (μg N g^{-1})	36.78 ± 4.86	63.31 ± 6.70
TOC (μg C g^{-1})	263.74 ± 2.09	402.24 ± 27.85
DOC (μg g^{-1})	23.92 ± 2.06	42.83 ± 2.30
pH (1:5)	8.84 ± 0.05	8.99 ± 0.04
EC (ms cm^{-1})	7.28 ± 0.06	2.92 ± 0.05

TC total carbon, *TN* total nitrogen, *TOC* total organic carbon, *DOC* dissolved organic carbon, *EC* electrical conductivity

2.3 Data analysis and statistics

Concentrations of total carbon (TC), total organic carbon (TOC), and total nitrogen (TN) in the original soil, and the incubated soil samples were quantified using vario MACRO element analyzer. For the pretreatment of removing total inorganic carbon (TIC), 1-g air dried soil was treated with 1 mol/L hydrochloric acid. And all soil samples were well mixed as 1:5 with deionized water. The pH and electrical conductivity (EC) of centrifuged solutions were then tested by portable pH meter and portable conductivity meter respectively. Shimadzu TOC analyzer (TOC-VCPH) was employed to analyze TOC. In our study, DROC was equal to the sum of daily CO_2-C emission rates and daily CH_4-C emission rates.

3 Results

3.1 Soil properties

As shown in Table 1, properties of two types of soil varied significantly with respect to TC, TN, TOC, DOC, and salinity ($p < 0.05$). TC, TN, TOC, and DOC were higher in the SS soil than BTF soil, and soil salinity in the BTF soil was almost 2.5 times of the SS soil. Table 2 shows the correlations between soil properties and DROC. A significant positive relationship was found between TC and TN, TOC, and DOC ($p < 0.05$), while a significant negative relationship was observed between EC and TC, TN, TOC, and DOC ($p < 0.05$). DROC was showed to significantly relate to DOC and pH (positive) ($p < 0.05$). From Table 2, pH showed insignificant relationships with soil carbon and nitrogen.

3.2 CO_2 and CH_4dynamics

We observed that the temporal dynamics and cumulative emissions of CH_4 as well as CO_2 are significantly different in each treatment (Fig. 1). Throughout 28-day incubation, the emission rates of CO_2 under different salt treatments decreased steadily and slowed down since the tenth day (Fig. 1). While the change of CH_4 emission rate was not distinct, CO_2 concentration of both types of soil were relatively high, and the emission rates plummeted rapidly in the early stage of experiment (0–9 days), and it is obvious that CO_2 concentrations in SS soil samples were far higher than that of BTF (Fig. 1). In the period of 10 days forwards, the rate speeded down in

Table 2 Product-moment correlation coefficients for properties of all soil samples

	TN (μg N g^{-1})	TC (μg C g^{-1})	TOC (μg C g^{-1})	DOC (μg g^{-1})	pH (1:5)	EC (ms cm^{-1})
TC (μg C g^{-1})	0.83*					
TOC, (μg C g^{-1})	0.78*	0.99**				
DOC (μg g^{-1})	0.78*	0.85**	0.90**			
pH (1:5)	0.44	0.25	0.24	0.42		
EC (ms cm^{-1})	− 0.74*	− 0.94**	− 0.92**	− 0.83*	− 0.4	
DROC (μg C g^{-1} d^{-1})	0.58	0.48	0.49	0.70*	0.88**	− 0.59

TN total nitrogen, *TC* total carbon, *TOC* total organic carbon, *DOC* dissolved organic carbon, EC electrical conductivity, *DROC* decomposition rate of organic carbon

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

a moderate manner (Fig. 1). It is evident that CH_4 emissions in both types of soil saw considerable fluctuations in the first half stage of the incubation and saw relatively plateau in the second half stage, while there were no distinct changes in their general trend (Fig. 1). However, it can be observed that CH_4 cumulative rates in almost all treatments here steadily increased in a constant rate (Fig. 2).

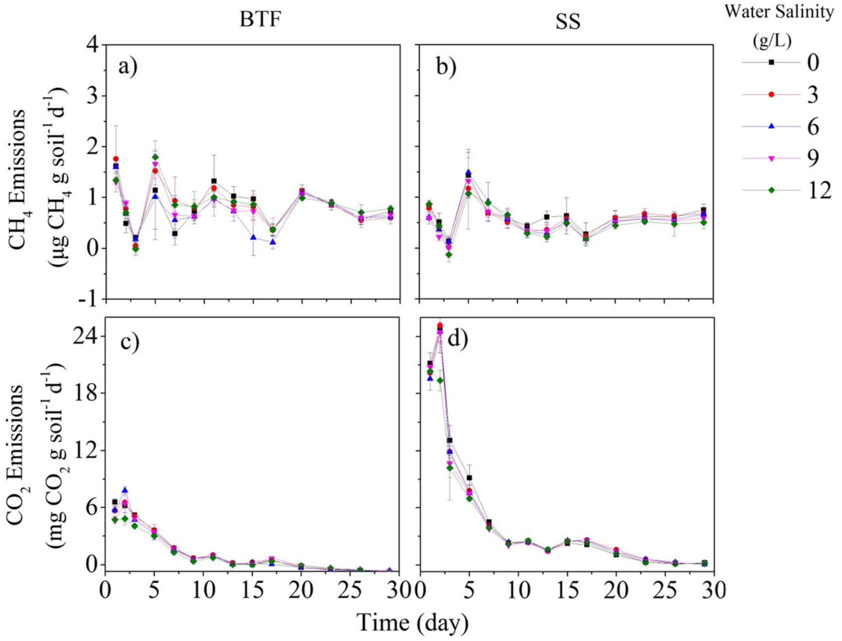
3.3 Decomposition rate of organic carbon

To better analyze the temporal variations of DROC under varying salinities, we divided the whole incubation into three phases and obtained the DROC of two types of soil in each phase (Table 3). DROC of the BTF and the SS showed similar trends during incubation, significantly higher in phase I than phase II and phase III ($p < 0.05$). However, DROC of the SS was significantly higher than the BTF in each phase ($p < 0.05$), and discrepancy even reached to almost five to eight times in phase II. As regards to the salt treatments, DROC of both types of soil were significantly inhibited with the increase of salt addition in phase I ($p < 0.05$), and the impact of soil salinity on DROC was not obvious in phase II and phase III (Table 3). Interestingly, we found DROC of the BTF in phase III was negative, which is still questionable and instructive for more detailed research.

3.4 Dissolved organic carbon

By comparing the original soil samples and the incubated samples, DOC in all salinity levels decreased. DOC of BTF soil samples' decrease change was significant and drop steadily along with the increase of water salinity from 29.61 to 64.89%. However, no significant difference of the DOC change (at 40~47.88%) was observed for SS soil. By investigating the decrease of DOC during the whole incubation, we

Fig. 1 Daily CO_2 (**a**, **b**) and CH_4 (**c**, **d**) emissions during the 28-day incubation of bare tidal flat (BTF: **a**, **c**) and Suaeda salsa (SS: **b**, **d**). The error bars indicate the standard deviations of quintuplicate measurements (n = 5)



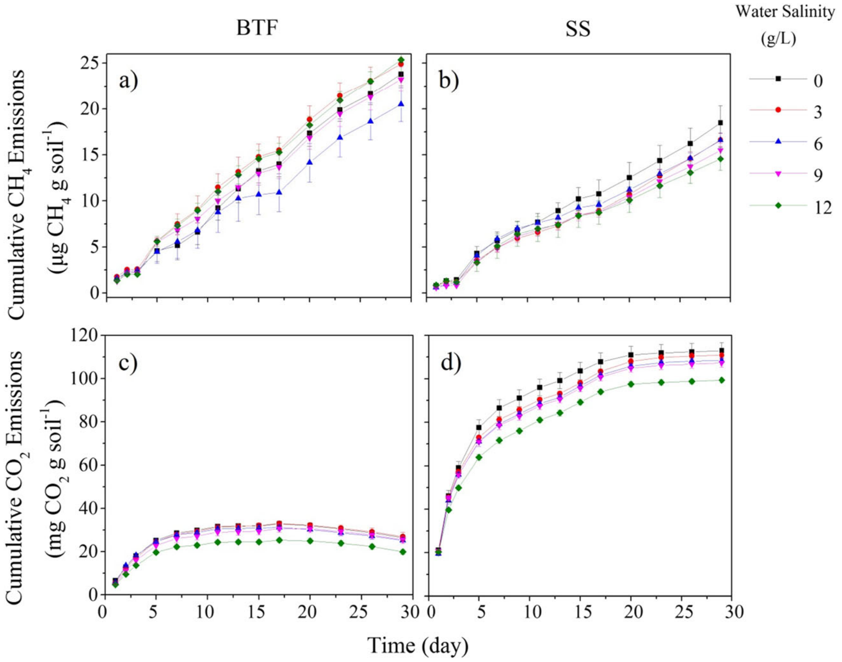


Fig. 2 Cumulative emissions of CO_2 (**a**, **b**) and CH_4 (**c**, **d**) during the 28-day incubation of bare tidal flat (BTF: **a**, **c**) and Suaeda salsa (SS: **b**, **d**). The error bars indicate the standard deviations of quintuplicate measurements ($n = 5$)

found the significant difference of DOC among salt-addition treatments in the BTF soil ($p < 0.001$) (Fig. 3a), while the negative relationship between soil salinity and DOC was not strong in the SS soil (Fig. 3b). And DOC of SS soil was apparently higher than DOC of BTF soil during the whole incubation.

3.5 Effect of salinity and DOC on decomposition rate of organic carbon

Previous studies showed that soil organic carbon mineralization is affected by many factors including soil salinity (EC) and organic carbon content (DOC) (Marton et al. 2012; Liu et al. 2017). To discuss the relationships between carbon mineralization and EC, as well as DOC, the partial correlation analysis was used to make comprehensive evaluation. We found the variations of partial correlation between DROC, and two environmental factors showed similar trends, with an increased R^2 in phase II (Fig. 4c, d) and a decreased R^2 in phase III (Fig. 4e, f). In phase I, EC showed great potential for inhibiting carbon decomposition rate ($R^2 = 0.47$, $p = 0.043$, Fig. 4a), while the effect of DOC was not significant. In phase II, the effect of DOC was greatly promoted ($R^2 = 0.80$, $p < 0.001$, Fig. 4d), and the negative effect of EC was highly improved ($R^2 = 0.93$, $p < 0.001$, Fig. 4c). In phase III, EC had a strong negative relationship with DROC ($R^2 = 0.89$, $p < 0.001$, Fig. 4e), while the effect of DOC on DROC was further weakened ($R^2 = 0.55$, $p = 0.021$, Fig. 4f).

Table 3 Decomposition rate of organic carbon (DROC) for each phase (phase I: days 1–8, phase II: days 9–18, phase III: days 19–28) during the 28-day incubation of soils from bare tidal flat (BTF) and Suaeda salsa (SS). Different numbers within a column or different letters within a row represent a highly significant difference ($p < 0.001$)

Water salinity g L^{-1}	0	3	6	9	12
			μg C g $soil^{-1}$ day^{-1}		
Phase I					
BTF	274.01 ± 4.63(a,1)	215.28 ± 7.71(b,1)	212.46 ± 7.88(bc,1)	200.38 ± 14.00(c,1)	169.27 ± 7.39(d,1)
SS	829.35 ± 35.32(a,2)	623.75 ± 8.73(b,2)	608.69 ± 9.21(b,2)	602.43 ± 14.34(b,2)	551.91 ± 3.32(c,1)
Phase II					
BTF	32.89 ± 6.25(ac,1)	32.06 ± 2.46(a,1)	20.11 ± 2.92(b,1)	31.11 ± 1.43(c,1)	20.75 ± 0.86(b,1)
SS	188.02 ± 4.45(a,2)	160.52 ± 4.87(b,2)	162.15 ± 4.01(b,2)	162.15 ± 3.95(b,2)	160.29 ± 3.769(b,2)
Phase III					
BTF	− 52.20 ± 5.06(a,1)	− 39.76 ± 8.95(b,1)	− 38.82 ± 2.00(b,1)	− 34.53 ± 2.29(b,1)	− 34.02 ± 2.79(b,1)
SS	32.16 ± 5.63(a,2)	40.94 ± 2.57(b,2)	36.30 ± 2.77(ab,2)	33.13 ± 3.19(a,2)	26.29 ± 2.45(c,2)

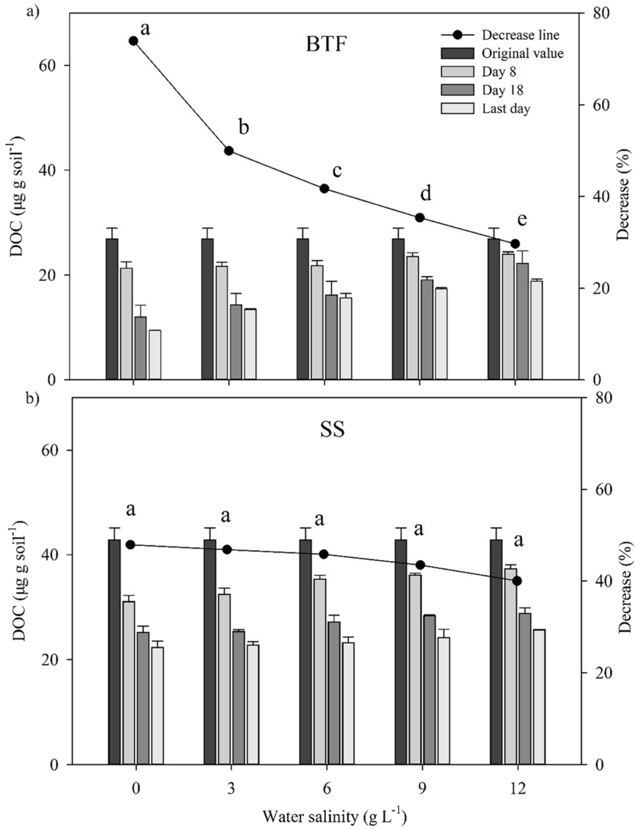


Fig. 3 Variations of dissolved organic carbon (DOC) and the percent decrease of DOC for each phase (phase I: days1–8, phase II: days 9–18, phase III: days 19–28) during the 28-day incubation of bare tidal flat (BTF: **a**) and Suaeda salsa (SS: **b**)

4 Discussion

4.1 Impact of soil salinity on decomposition rate of organic carbon

Salinity is a substantial environmental stressor with the potential to change the trend and rate of carbon cycling in wetlands, especially with the existence of periodical water stress and salt stress (Sangiorgio et al. 2008; Wong et al. 2008; Chambers et al. 2011; Wang et al. 2016). Soil CO_2 emissions were shifted with time (Figs. 1 and 2) and showed similar patterns in different types of soil (BTF and SS), with rapid rates in the early days and gradually slower rates in the mid-term and later period of incubation (Cheng et al. 2008; Maucieri et al. 2017). The fluctuation of soil CO_2 emissions in the incubation, with no added carbon, was substantially controlled by the availability of labile carbon, with heterotrophic consumption of labile carbon in the beginning and exhaustion of labile carbon in the later period (Zimmerman et al. 2011). The concentrations of TC and MBC showed a general deceasing tendency with increasing salinities in the top 30 cm of soils in degraded coastal wetlands (Zhao et al. 2017). Corresponding to great difference of the soil carbon content (TC, TOC, DOC) between BTF and SS (Table 1), we found the rate of CO_2 emission of SS was much higher than the BTF soil (Fig. 1), with the peak rate of the SS soil (24.9 mg CO_2 g soil^{-1} day^{-1}) was 3.83 times of the BTF soil. Interestingly, unlike the adverse effect on CO_2 production, the relationship between soil salinity and CH_4 emissions was complex for the BTF soil (Figs. 1 and 2), which, in line with previous studies (Ardon et al. 2016, Liu et al. 2017), showed the formation of CH_4 may be influenced by not only soil salinity, moisture, and available carbon but also competition between methanogen and other strictly anaerobic microorganisms (i.e., sulfate reducers and Fe (III)-reducers). Meanwhile, previous laboratory incubations (Maucieri et al. 2017; McDaniel et al. 2017) revealed that brief periods of CH_4 emission always followed by sustained oxidation and mostly showed no distinct patterns, which are also consistent with our results. Our study cannot clearly explain the different impact of soil salinity on CH_4 emissions for the BTF and SS soil; however, vegetation has direct and indirect effect on microbial biomass and microbial activity (Nathaniel et al. 2011) and it might be enlightening for further research.

To better understand the variation of DROC, determined by adding CH_4-C and CO_2-C, we divided the whole incubation into three phases (Table 3) and found obvious decrease of DROC between the former and the later phase. DROC generally showed negative correlation with soil salinity in phase I ($p < 0.001$), and the difference of DROC among five treatments were much smaller in phase II, even negligible in phase III (Table 3). On the contrast, using partial correlation analysis to control DOC variables (Fig. 4), we found the relationship between soil salinity and DROC in phase I was weak ($R^2 = 0.47, p < 0.05$), with a significant negative correlation in phase II and phase III ($p < 0.001$). Soil salinity and DOC synthetically influenced DROC (Liu et al. 2017) and, in particular, soil salinity affects solubility and mobility of DOC (Ardon et al. 2016). Therefore, it is necessary to analyze the impact of salinity on DROC with the removal of effect from DOC.

In our study, we found the impact of soil salinity on DROC varied along with temporal change, and the highest inhibition effect was observed in phase II. These findings, notwithstanding, did not address whether ionic stress alone affect microbial respiration and DROC. To better understand the mechanism of how salt ionic influence DROC, it may be an effective way to research the relationship between microbial biomass carbon (MBC), and to analyze whether microbial community structure or diversity could be altered by the NaCl addition (Baldwin et al. 2006). This could be a limitation of our experiment design.

4.2 Impact of soil DOC on decomposition rate of organic carbon

Positive correlations between DROC and DOC were found in tidal wetlands (Cook and Allan 1992; Chow et al. 2006). By investigating the variation of DOC (Fig. 3) and DROC of different phases (Table 3), we confirmed the more labile

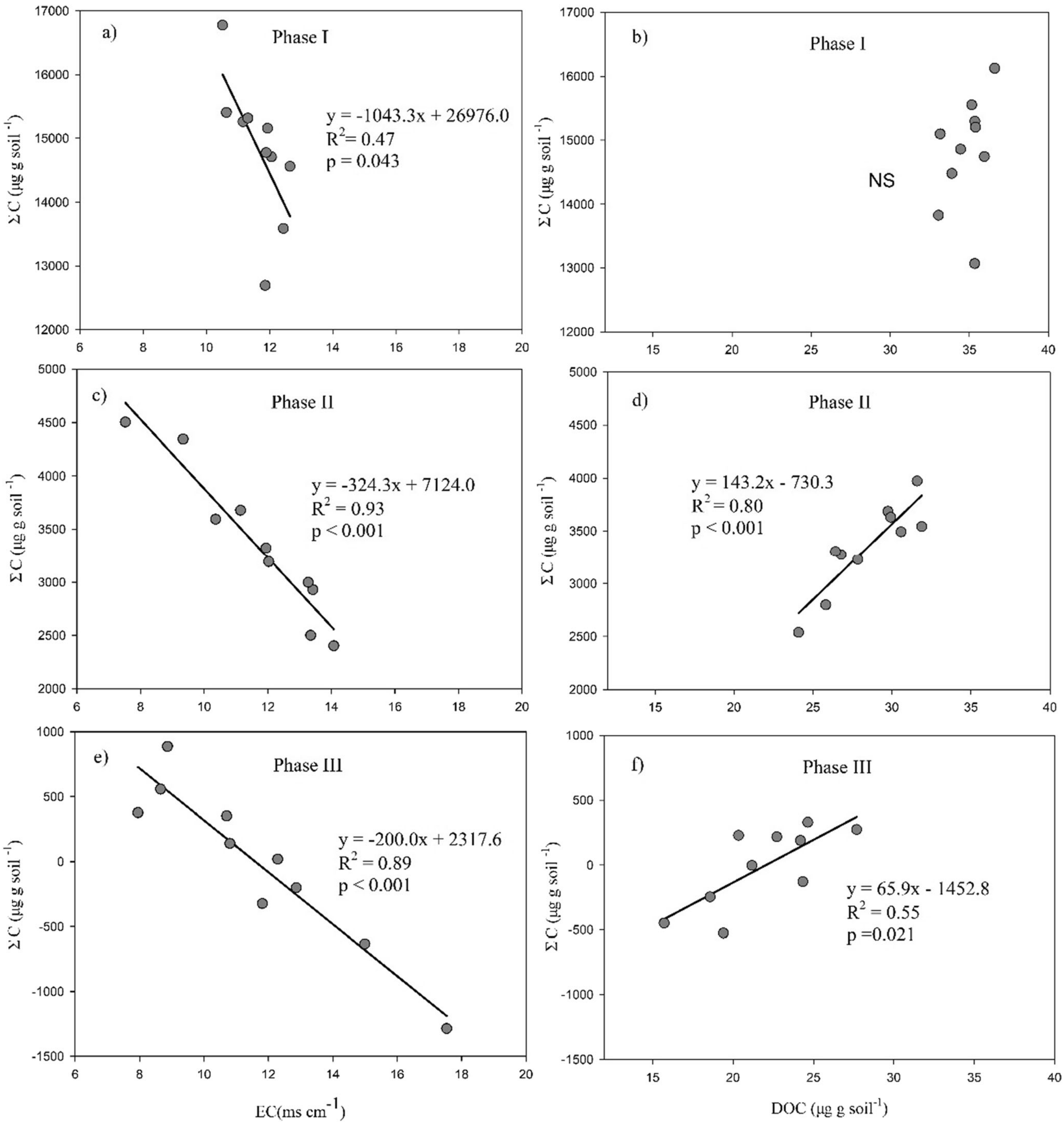


Fig. 4 Relationships between decomposition rate of organic carbon (DROC) and electrical conductivity (EC) (**a** phase I, **c** Phase II, **e** Phase III) and between DROC and dissolved organic carbon (DOC) (**b** Phase I, **d** phase II, **f** phase III) analyzed by the partial correlation-based method. Phase I days 1–8, phase II days 9–18, phase III days 19–28

carbon (e.g., DOC) soil contained, the higher DROC was observed. In this study, SS was observed 72.83 μg g^{-1}, which is nearly 1.79 times of the BTF soil (Table 1). The main reason for this discrepancy might be that increasing salinity will lead to a decrease in microbial biomass and activity, and consequently cause slower DOC decomposition rates by affecting solubility and mobility of DOC (Baldwin et al. 2006; Marton et al. 2012; Setia et al. 2013).

We investigated the relationship between DOC and DROC in three phases, by controlling the variables of soil salinity (Fig. 4). And our study concluded that DROC was not linearly proportional to DOC concentration, and DOC showed stronger promoting effect ($R^2 = 0.80$, $p < 0.001$) on DROC in the middle of incubation (days 9–18), comparing to the early (days 1–8) and the later (days 19–28) ($R^2 = 0.55$, $p < 0.05$) period of experiment. To demonstrate the contribution of different carbon concentrations and fractions (DOC, SOC, total available organic carbon) on formation rates of CO_2 and CH_4, DROC showed linearly positive relationship with DOC with the application of a kinetic model (Chow et al. 2006; Liu et al. 2017). The primary reason accounting for the inconsistence of results between our study and previous studies, apart from variations of experimental designs and observations, might be the lack of observing DOC production. DOC could be produced by microbes' utilization of SOC as carbon source during incubation (Moore and Dalva 2001, Chow et al. 2006, Liu et al. 2017). Accordingly, the actual consumption of DOC in phase I must be higher than we observed (Fig. 3). In addition, DOC production is related with SOC and microbial biomass (Zhang et al. 2007a, b); it will gradually decrease due to reduction of SOC concentration and microbial biomass. Therefore, total decrease of DOC in different phases might have linearly positive relationship with DROC if above-mentioned possibility was considered.

4.3 Limitations

To better understand the mechanism of how soil salinity and DOC affect DROC, we should not only investigate the gas emissions above the soil, but also analyze the microbial biomass and activity under the ground, which is the limitation of our experimental design. Previous studies have proved MBC can be a reliable indicator of observing microbial biomass and activity, especially in the production of greenhouse gases (Moore and Dalva 2001; Chow et al. 2006; Nathaniel et al. 2011; Liu et al. 2017). In our experiment, the difference of soil salinity before and after adding salt was not significant due to high salinity of original soil (Table 1). This is properly accounting for negligible differences of CO_2 emissions between different treatments (Fig. 1). Besides, the variation of SOC should be taken into consideration when we analyze the DOC production and the impact of soil DOC on DROC.

5 Conclusions

This study demonstrated that increased soil salinity had a negative effect on DROC during 28-day incubation, with five constant-gradient salt addition to different types of soil from tidal salty marsh wetland. DROC was not linearly proportional to DOC concentration, and DOC showed strong promoting effect ($R^2 = 0.80$, $p < 0.001$) on DROC in the middle of incubation (days 9–18). In addition, the impact of soil salinity and DOC were varied in different phases of laboratory experiment. These results suggest that higher salinity of YRD tidal soil will have direct or indirect suppression on microbial respiration, especially for CO_2 emissions. The land cover was confirmed to be a significant factor of soil properties, and the SS soil was observed higher available carbon and lower salinity than the BTF soil. Our original hypothesis the decrease rate of DOC would have a positive relationship with DROC was not strongly supported by our observation. However, the DOC production from SOC might account for the inconsistence and it is enlightening to combine different carbon sources with microbial respiration in the future research of carbon cycling in YRD wetland. Further work should focus on salinity impacts on carbon mineralization in both natural and manipulated in the lab, and linking microbial community shifts (microbial biomass and activity) to DROC.

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