Decomposition and return of C and N of plant litters of *Phragmites australis* and *Suaeda salsa* in typical wetlands of the Yellow River Delta, China

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Abstract

Litter decomposition is the key process of nutrient cycling and energy flowing in wetlands, which is also one of the important processes to maintain wetland ecosystem functions. The litter decomposition and C and N returns of *Phragmites australis* and *Suaeda salsa* were investigated during the growing period in typical wetlands of the Yellow River Delta with different flooding frequencies using litter bag technique in order to study the effects of flooding frequencies on litter decomposition and nutrient return of wetland plants. The results showed that during the study period, the litter weight loss rate and C return rate of *Phragmites australis* were lower than those of *Suaeda salsa*, while N return rate (64.3\%) was higher compared to *Suaeda salsa* (43.3\%) under the same flooding patterns. Flooding frequency had a significant effect on the processes of litter decomposition and nutrients returns of *Phragmites australis* and *Suaeda salsa*. Seasonally-flooded *Phragmites australis* had the highest decomposition rate, but the tidally-flooded *Phragmites australis* had a higher N return rate. However, the C return rate of the short-term-flooded *Phragmites australis* showed higher values in respective to others. *Suaeda salsa* had higher return rates of C and N elements and weight loss rate in tidally flooded wetlands than those in in short-term-flooded wetlands.

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Key words: Litter decomposition; C; N; Return rate; Flooding frequency

1. Introduction

Plant litter is the main component of net primary production and an important source of nutrients in wetland ecosystems. Once the litters falling to the soil surface they will be decomposed due to the influences of various environmental factors, thus releasing nutrients (e.g. C and N) to soil pool\textsuperscript{[1]} Most researches have focused on litter decomposition of wetland plants \textsuperscript{[2-5]} and their influencing factors \textsuperscript{[6-8]}. Recently, the processes of litter decomposition in wetland ecosystems have become an international hotspot in wetland study field. In contrast, the litter decomposition in wetlands was only thrown much light on in China in recent years. Wu et al. \textsuperscript{[9]} and Liu et al. \textsuperscript{[10]} presented the decomposition process, decomposition speed and residual rate of litters and nutrient returns of...
Angustifolia, Carex lasiocarpa and rafting Carex in freshwater wetlands (e.g. Sanjiang Plain wetlands). Wu et al. [1, 9] still investigated the effects of important environmental factors such as initial litter weight, soil moisture content and soil temperature on plant litter decomposition. Additionally, Song et al. [11] reported that soil animals had important influences on litter decomposition and changes of calorific value. However, little information is available on the effects of flooding frequency on the litter decomposition in wetlands [11].

Flooding frequency is an important factor influencing litter decomposition in wetlands, because it could directly affect litter decomposition through changing soil moisture content or water levels, and it could also lead to the variations of environmental factors such as temperature, environment, nutrient availability, pH, Eh, dissolved oxygen concentration, salt salinity etc. Therefore, the primary objective of this study are to litter decomposition and nutrient release in different wetlands with different flooding frequencies in the Yellow River Delta, and to reveal their important influencing factors.

2. Materials and Method

2.1. Study area

The Yellow River Delta (N37° 35'-38° 12', E118° 33'-119° 20') is the most complete, extensive and youngest wetland ecosystem in China’s warm temperate zone, which is located in Dongying city, Shandong Province. The study area is in the East Asian monsoon mid-latitude temperate semi-humid continental climate zone, with its annual average temperature of 12.3 °C, annual sunshine rate of 62%, and annual average sunshine of 2682 h. The peak sunshine hour appears in May, while the lowest in December. The average frost-free period is 210 d, and the annual average wind speed is 3.1-4.6 m/s. The average annual rainfall is 551.6 mm, and most of them concentrated in summer (63.9%), especially in July and August, which mainly caused the summer flooding and the main local waterlogging. Its annual evaporation is 1962.1 mm and particularly strong in spring, and accounts for 51.7% of the year. Soil salinization in the region is severe (up to 70%), and plant species’ diversity is very high, but the plant community composition is simple with less constructive species.

2.2. Sample collection and experiment design

We have chosen three typical plots with different flooding frequencies based on the typical and representative principles, including short-term-flooded wetlands (overwetted because of higher belowground water level; North bank of the Yellow River), seasonally-flooded wetlands (old course of the Yellow River) and tidally-flooded wetlands (tidal areas of the estuary). In early November 2007, we collected aboveground biomass of Phragmites australis and Suaeda salsa in typical wetlands of the Yellow River Delta, which represents the initial state of plant litters to be decomposed in the coming year. These plant aboveground parts were air dried at room temperature after soil and other impurities were removed.

For this experiment, litter bag technique was used to research the litter decomposition of Phragmites australis and Suaeda salsa. The bags are made up with 60 nylon mesh, with the bag size of approximately 20 cm × 20 cm. The dry samples of Phragmites australis and Suaeda salsa were cut and then fully mixed, weighed and bagged. 10 g plant sample was placed into each bag. There are in total of 5 experimental plots (including three Phragmites australis plots and two Suaeda salsa plots). In total of 30 sample bags were placed on the soil surface of each experimental plot in May. After that, every 10 bags were randomly sampled in August, October and November at each plot for laboratory analysis.
2.3. Sample processing and analysis

After cleaning the sediment and other debris on the surface, plant litter samples were dried in an oven at 40 °C for 8-10 hours to constant weight and then calculated the weight loss. The dried plants were milled using a jet milling and then passed the 20 nylon sieve. Total C and N contents in plant litters was determined with elemental analyzer (CHNOS Elemental Analyzer, Vario EL, German).

2.4. Data Processing

(1) Weight loss rate of plant litters:

\[ DW_i = \left( \frac{\Delta W}{W_0} \right) \times 100\% \]  

\( DW_i \) - rate of weight loss at time \( i \);
\( \Delta W \) - weight loss of plant litters (g);
\( W_0 \) - initial litter weight;

(2) Net return rate of C or N of plant litters:

\[ E_i = \left[ \frac{(e_0 - e_i)}{e_0} \right] \times 100\% \]

\( E_i \) – net return rate of C or N at time \( i \) (%);
\( e_i \) – C or N residue in plant litters at time \( i \) (g);
\( e_0 \) – initial C or N content in plant litters (g).

(3) Data Statistics

Data statistics were carried out using SPSS16.0 and Excel2003 software packages. One-Way ANOVA was performed to identify the differences of the decomposition rates and C or N return rates of different plant litters or same plant litters under the conditions of different flooding frequencies. Use Two-Way ANOVA was conducted to reveal the affects of time and experimental plots (flooding frequency) and their interactions on the decomposition rate and C or N return rate of plant litters. The results were considered significant if \( p <0.05 \).

3. Results and Discussion

3.1. Litter decomposition and C or N return of different wetland plants

Litter decomposition rates of \textit{Phragmites australis} and \textit{Suaeda salsa} were compared under the tidally-flooded conditions. Table 2 shows the dynamic changes of average residual weight of \textit{Phragmites australis} and \textit{Suaeda salsa} litters in different months. The weight loss of the litters of \textit{Phragmites australis} and \textit{Suaeda salsa} showed an increase with increasing months. The rates of weight loss of both plants also showed similar changing tendency with time (Figure 2). The decomposition rates of \textit{Suaeda salsa} litters was higher than those of \textit{Phragmites australis} (\( p <0.01 \)). For \textit{Phragmites australis} litter, the weight loss rate increased rapidly before October and then showed an slow increase after October. Similarly, the weight loss rates of \textit{Suaeda salsa} showed rapid increase before October, while a slow decrease tendency were observed after October. The rapid increase of the weight loss could be
explained by the fact that a lot of soluble organic particles and inorganic salt were lost at the beginning of litter decomposition since the main decomposition way was physical leaching, while the weight loss rates deceased or slowly increased with the increase in insoluble matter content increasing [9]. Additionally, air temperature decreased after October also could prohibit litter decomposition.

Table 1 The average residual weight of the litters of *Phragmites australis* and *Suaeda salsa*

<table>
<thead>
<tr>
<th></th>
<th>May</th>
<th>August</th>
<th>October</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Phragmites</em></td>
<td>9.45</td>
<td>9.04</td>
<td>7.54</td>
<td>7.35</td>
</tr>
<tr>
<td><em>Suaeda salsa</em></td>
<td>9.45</td>
<td>6.78</td>
<td>5.39</td>
<td>5.77</td>
</tr>
</tbody>
</table>

Figure 2 The weight loss rates of *Phragmites australis* and *Suaeda salsa* litters

Figure 3 The net N return rate of *Phragmites australis* and *Suaeda salsa* litters
Figures 3 and 4 show respectively nitrogen and carbon return rates of *Phragmites australis* and *Suaeda salsa*’s litters under the tidally-flooded conditions. N return rates showed slow increase before October while slow decrease after October (Figure 3). The N release from plant litters accounted for 63.4% (*Phragmites australis*) and 43.3% (*Suaeda salsa*) of the initial N contents in litters. In contrast, N return rates of *Phragmites australis* litters were significantly higher compared to *Suaeda salsa* litters (p < 0.01), which might be related to higher initial N contents in *Phragmites australis* litters. However, C return rates showed consistent changes with that of weight loss rates of plant litters (Figures 2 and 4). Before October, the C return rate of *Phragmites australis* litters was less than that of *Suaeda salsa* (p < 0.05), while the C return rates of both plant litters reached similar values after October. Both C and N return rates of both plant litters were controlled by litter decomposition. Due to higher air temperature and plenty rainfall during the period from June to August in the yellow River Delta, it could improve microbial activity, thus leading to the fast phase of litter decomposition. After October the decrease of air temperature and soil moisture prevented microbial activities, which inhibited the decomposition process of physical and chemical processes, therefore the lower return rate of C and N.

### 3.2. Effects of flooding frequency on decomposition and C or N return of *Phragmites australis* litter

Figure 5 shows the decomposition rate of *Phragmites australis* litters in three wetlands with different flooding frequencies (seasonally-flooded, tidally-flooded and short-term-flooded wetlands). Higher weight loss rates of were observed in *Phragmites australis* litters in the seasonally-flooded wetland compared to those of tidally-flooded and short-term-flooded wetlands. The decomposition rates of *Phragmites australis* litters showed the tendency of “increasing before decreasing” in seasonally-flooded wetland, while they kept increasing during the growing period in another two wetlands. In November the decomposition rates of *Phragmites australis* litters reached similar values in three wetlands. Despite high salinity could inhibit microbial activity, leading to low litter decomposition [12], *Phragmites australis* litters in the seasonally-flooded wetland with higher soil salinity in this study showed a higher decomposition rates. This might be because seasonal flooding alleviated the salinity stress on organisms.
Figure 5  Weight loss rates of *Phragmites australis* litters in three wetlands with different flooding frequencies

Figure 6  Net N return rates of *Phragmites australis* litters in three wetlands with different flooding frequencies
Figures 6 and 7 show N and C return rates of *Phragmites australis* litters in three wetlands with different flooding frequencies. Net N return rates of *Phragmites australis* litters in seasonally-flooded and tidally-flooded wetlands showed similar decreasing tendency with increasing month while they rapidly decrease before October while showed a slow increase after October in the short-term-flooded wetland. Generally, higher N return rates were observed in the tidally-flooded wetland (Figure 6). However, N return rate of *Phragmites australis* litters showed the highest values in August in the short-term-flooded wetland. However, C return rates of *Phragmites australis* litters kept increasing with time in the tidally-flooded and short-term-flooded wetlands. They showed an increase before October and a decrease after October (Figure 7). This was likely related to the fact that the short-term flooded wetlands that on the North bank of Yellow River had lower soil salinity, which could contribute to the organisms’ activities [12].

Table 2 shows the statistical results of two-way ANOVA analysis of different flooding frequencies and sampling months on decomposition and C and N returns. From Table 2, we could observe flooding frequency and sampling month had significant influences on the residual weight, carbon and nitrogen content of *Phragmites australis* litters, but their interactions was not significant, and only had significant effect on nitrogen dynamics (p < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Residual weight</th>
<th>C content</th>
<th>N content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding frequency</td>
<td>0.013</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Sampling month</td>
<td>0.000</td>
<td>0.030</td>
<td>0.000</td>
</tr>
<tr>
<td>Flooding frequency*sampling month</td>
<td>0.051</td>
<td>0.094</td>
<td>0.045</td>
</tr>
</tbody>
</table>
3.3. Effects of flooding frequency on decomposition and C and N returns of Suaeda salsa litter

Figure 8  The weight loss rates of Suaeda salsa litters in tidally-flooded and short-term-flooded wetlands

Figure 8 illustrates changes in the weight loss rates of Suaeda salsa litters with increasing months under two flooding frequency conditions (tidal flooding and short-term flooding). As Figure 8 shown, the rates of weight loss were significantly higher in tidally-flooded wetland than those in the short-term-flooded wetland (p <0.01). This indicated that tidal flooding contributed to decomposition of Suaeda salsa litters in a certain extent. Despite the weight loss were higher in the tidally-flooded wetland after October, it showed a slow decrease. The decreased decomposition was likely related to tidal flooding. Though seawater tidal could increase soil moisture, the overwetted conditions would reduce Eh and available oxygen [10], moreover, soil salinity would be elevated, thus inhibiting the decomposition of plant litters. In contrast, the rate of weight loss increased rapidly before October while became slow increase after October. The lower air temperature after October might be an important reason to lead the decrease or increase of the decomposition rate.

Figure 9 N return rates of Suaeda salsa litters in tidally-flooded and short-term-flooded wetlands
Figures 9 and 10 show the return rates of N and C of Suaeda salsa litters in tidally-flooded and short-term flooded wetlands. From Figure 9, higher N return rates of Suaeda salsa litters were observed in tidally-flooded wetlands compared to the short-term-flooded wetlands (p<0.01). The N return rates of Suaeda salsa litters showed a rapid increase before October while a slow decrease after October in the tidally-flooded wetland. However, they showed obvious decline, especially after October in the short-term-flooded wetland. Similarly, the C return rates of Suaeda salsa litters were also higher in the tidally-flooded wetlands than those in the short-term-flooded wetlands (p<0.05, Figure 10). Moreover, they consistently showed the tendency of “increasing before decreasing” in the tidally-flooded wetlands. However, in the short-term flooded wetlands, they kept increasing during the growing season, which is in agreement with the change of the decomposition rates of Suaeda salsa litters. This indicated that tidal flooding could improve N and C release from Suaeda salsa litters compared to the short-term flooding. This was because tidal flooding (e.g. flood tide and ebb tide) had scouring effect on the litters, which accelerated the leaching effect and promoted litter’s decomposition and C and N return. Additionally, the frequent tidal flooding will cause sedimentation, which could slow down the litter’s decomposition by directly or indirectly mechanisms, such as changing the chemical characteristics of the surrounding water, having physical compaction on litter’s debris and reducing the gas and nutrient exchange between the debris layer and surrounding water environment, and inhibiting bacteria, fungus, algae, invertebrates and other organisms’ decomposition activities [13].

Table 3 shows the statistical results of two-way ANOVA analysis of different flooding frequencies and sampling months on decomposition and C and N returns of Suaeda salsa litters. From Table 3, flooding frequency and sampling month had great influences on the residual weight (p<0.01) and C and N release (p<0.05) of Suaeda salsa litter. Moreover, their interaction effects on C and N release was also significant (p<0.05), i.e. tidal flooding contributed litter decomposition of Suaeda salsa.

Table 3 Statistical analysis of two-way ANOVA analysis of flooding frequency and sampling months on the decomposition and C and N returns Suaeda salsa litters

<table>
<thead>
<tr>
<th></th>
<th>Residual mass</th>
<th>C content</th>
<th>N content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding frequency</td>
<td>0.000</td>
<td>0.063</td>
<td>0.004</td>
</tr>
<tr>
<td>Sampling season</td>
<td>0.000</td>
<td>0.027</td>
<td>0.006</td>
</tr>
<tr>
<td>Flooding frequency* Sampling season</td>
<td>0.136</td>
<td>0.001</td>
<td>0.016</td>
</tr>
</tbody>
</table>
4. Conclusions

The decomposition rates of *Phragmites australis* and *Suaeda salsa* litters are different when under the same flooding frequency. *Phragmites australis* litter’s decomposition rate and C return rate are lower than those *Suaeda salsa*’s litter, while the release rate of N is higher compared to *Suaeda salsa*’s litter. Flooding frequency has significant affect on *Phragmites australis* litter’s decomposition and nutrient return rate. Seasonal flooding is beneficial to *Phragmites australis* litter’s decomposition, but not improving the return of C and N. However, different flooding frequencies have significant affects on C and N return rates of *Sueda salsa* litters. Tidal flooding pattern can promote the litter’s decomposition and C and N release. The findings of this study can provide a scientific basis for wetland conservation and management, and restoration and reconstruction of degraded wetland in the Yellow River Delta or other coastal wetlands.

References