Research Article

Effects of Water Level and Salinity on TN and TP Contents in Marsh Soils of the Yellow River Delta, China

A field experiment was carried out at three different water levels and four salinity levels to study the effects of water level and salinity on nutrient contents in marsh soil of the Yellow River Delta, China. Contents of total nitrogen (TN) and total phosphorus (TP) in surface and subsurface soils were measured under different water and salinity levels during the study period. Results showed that TN contents gradually decreased with increasing salinities and the highest content appeared in surface soils in different sampling dates. Higher TN contents in August (361.55 mg/kg) and September (412.17 mg/kg) were observed under 0.52 and 16.7% salinity treatments, respectively, and 10 cm water level, and the highest value in October (504.81 mg/kg) was observed under 10.2% salinity treatment and 0 cm water level. TN contents showed significant differences among different water treatments. Similarly, TP content also appeared an accumulation in surface soils in each sampling date. However, significant differences of TP contents in subsurface soils were observed among three water levels. Salinity significantly influenced the changes in TN and TP contents in both soil layers under different water level treatments. Soil TN and TP contents were significantly correlated to soil organic matter.

Keywords: Flooding; Nutrient; Salt marsh; Soil organic matter

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1 Introduction

Limiting nutrients are a function of hydro-chemical environments and the nutrient requirements of different species [1]. Nitrogen (N) and phosphorus (P) are often considered as the important limiting nutrients of wetland ecosystem which greatly influence the primary productivity of wetland ecosystem [2–4]. Aerts and Chapin [5] also presented that vascular plant growth was limited by the availability of N or P relative to plant growth requirements. Soil nutrients can be influenced by many environmental factors. Most researchers have reported that the changes of soil nutrients in wetland ecosystems were closely related to soil properties such as soil organic matter (SOM) [6], clay contents [7], soil pH [8], and temperature [9]. However, little information is available on the effects of water level and salinity on soil nutrients in coastal wetlands.

Estuaries are important coastal wetlands and serve as the ecotones of freshwater and seawater, which are significantly influenced by salt ions of seawater. McLuskey [10] demonstrated that salinity could control the distribution pattern of particular organisms. Meanwhile, the contents and their distribution of soil nutrients (i.e., N and P) can also be influenced by salinity [7]. Some researchers showed that the N/P ratio of water and plants in different estuaries considerably varied with the changes of salinity [11]. Doering et al. [12] found a transition from P to N limitation somewhere along a salinity gradient.

Water level is one key factor influencing wetland ecosystem (including estuaries). It has been reported that hydro-period considerably influenced the concentrations, forms, and transformation of soil nutrients and plant productivity in wetland ecosystem [4, 13]. Aldous et al. [14] and Dunne et al. [15] presented that hydrological factors such as drawdown and antecedent hydrological conditions could greatly influence P dynamics between soil and water. Pant and Reddy [16] also observed that P released from P-loaded soils decreased as the number of flood cycle increased. Numerous studies have focused on the effects of changes in water and salt contents on wetland species in coastal region [17–21] and nutrient distribution in mash soil [7, 13]. However, little information is available on the combined effects of salinity and water level under different levels on nutrients (i.e., N and P) of mash soil, especially in coastal wetlands.

The primary objectives of this study are (i) to investigate the changes in the contents of total nitrogen (TN) and total phosphorus (TP) in wetland soils with different water levels and salinity treatments; (ii) to reveal the influences of water level and salinity on TN and TP contents in wetland soils.

2 Materials and methods

2.1 Study area

The Yellow River Delta is located in Dongying City of Shandong Province, China (37°35′–38°12′N, 118°33′–119°20′E). It is the most complete and youngest wetland ecosystem in China’s warm
temperate zone which covers approximately $15.3 \times 10^4$ hm$^2$. The study area is in the East Asian monsoon and the mid-latitude temperate semi-humid continental climate zone, with its annual average temperature of 12.3°C, annual average sunshine of 2682 h and annual evaporation of 1962.1 mm. The annual average precipitation is 551.6 mm, and most of them concentrate in summer (63.9%), especially in July and August. Soil salinization in the region is serious (up to 70%) and the dominant vegetations are Phragmites australis and Suaeda salsa in the study area.

2.2 Experiment design and sample collection

A $3 \times 4$ factorial experiment was designed, with three water levels (0, 10, and 15 cm, which were represented by A, B, and C, respectively) and four salinity treatments (0.52, 10.2, 16.7, and 27.36%, which were represented by FW, FS, SF, and SW; Fig. 1) in a typical plot with pure P. australis community which was suffering from the effects of seawater tides. Salinity and water level were controlled by a device consisting of two PVC pipes. One pipe (65 cm long, 16 cm diameter) was inserted into the soil deep to 50 cm, and then dug the pipe out. After the bottom of the pipe was covered by plastic membrane to prevent from underground water, the pine with soil was replaced into the original hole in the sampling plot. A little gap was made on the top part of the pipe to control water level. Another bigger pipe (55 cm long, 20 cm diameter) was set outside of the above mentioned pipe and inserted into the soil (20 cm) to protect inside pipe from flooding of the seawater tide (the maximum height of tide at this plot is 30 cm; Fig. 2).

All the soils in pipes were pre-incubated for 2 months in order to avoid the disturbance of initial salt contents in wetland soils. Three same pipe-devices were designed for each water level and salinity treatment. Soil samples were collected from 0 to 20 cm depth and transected into two layers at 10 cm intervals in July, August, and September of 2008, respectively. Soil samples were randomly collected in two pipes among the three replicates. It is noted that the hole with plastic bag was filled with fresh soil in the pipe after collecting soil samples. This can contribute to retaining soil structure and carrying out further incubation. All samples were sealed and brought back to the laboratory.

2.3 Sample processing and analysis

Recognizable plant litters, stones and other impurities were removed. Subsamples were air-dried under natural condition for 3 wk, mixed well, ground, and sieved using a 100-mesh sieve, and then stored in a plastic zip-lock bag before analysis. TN content was determined using elemental analyzer (CHNOS Elemental Analyzer, Vario EL, and German). TP content was measured using
inductively coupled plasma-atomic emission spectrometry (ICP-AES). SOM was determined following the method described by Walkley and Black [22]. Available phosphorus (AP) was measured using the Olsen bicarbonate extractable P method [23]. Nitrate nitrogen (\(\text{NO}_3^{--}\text{N}\)) was determined by the phenol-two-sulfonic acid method.

2.4 Statistical analysis and graphing

One-way ANOVA was used to identify the differences of TP and TN contents among different sampling dates and soil layers. Two-way ANOVA was conducted to reveal the effects of water level, salinity, and their interactions on TN and TP contents in mash soils. Statistical analyses were performed using SPSS 16.0 statistical package, and differences were considered significant if \(p < 0.05\). Surface maps for spatial distribution of TP and TN were conducted using Suffer 8.0 software package.

3 Results and discussion

3.1 Effects of water level and salinity on TN contents in mash soil

Figure 3 shows the variations in TN contents along soil profiles from 0 to 20 cm under three water levels and four salinity treatments. Higher TN contents in August (361.55 mg/kg) and September (412.17 mg/kg) were observed under 0.52 and 16.7% salinity treatments, respectively, with 10 cm water level, while the highest value in October (504.81 mg/kg) was observed under 10.2% salinity treatment and 0 cm water level. TN contents showed significant differences among different water level treatments. As shown in Tab. 2, water level only had significant effects on TN contents in surface soils. Bai et al. [7] presented that water level might be one of important factors influencing N contents, because water level fluctuations

![Surface map for TN distribution of mash soils along different water levels and salinity treatments.](image-url)
could greatly affect nitrogen transformation and movement. Walbridge and Struthers [24] also reported that low water tables might reduce the possibilities for nutrient retention through plant uptake and nitrogen removal through denitrification. The peak TN contents in surface soils were observed under a moderate salinity level (such as FS or SF). It might be closely linked to microorganism activities which controlled the decomposition rate of plant litters because the microorganism can be activated under appropriate conditions.

Total nitrogen contents in surface soils (0–10 cm) gradually decreased with increasing salinities in August of 2008. Moreover, salinity had significant effects on TN contents in the top 20-cm soils (Tab. 2). This was in agreement with the result, reported by Chen and Twilley [25], that relative nitrogen mineralization in mangrove soils exponentially decreased with decreasing salinities. However, Fang et al. [26] and Lodhi et al. [27] reported that organic nitrogen mineralization decreased with increasing salinities. Additionally, nitrogen immobilization, leaching, ammonia volatilization, and denitrification can also lead to nitrogen loss from marsh soils [25, 28, 29]. Xu et al. [30] reported that higher salinity might contribute to ammonia volatilization. In this study, we could observe the increasing changes of TN contents in surface soils with incubation time.

<table>
<thead>
<tr>
<th>Table 1. Relationship between TN and NO₃⁻–N contents</th>
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<tr>
<td></td>
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<tr>
<td>Pearson</td>
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<tr>
<td>Sig. (2-tailed)</td>
</tr>
</tbody>
</table>

**Figure 4.** Surface map for TP distribution of mash soils along different water levels and salinity treatments.
This could be explained by the fact that nitrogen could be returned to surface soil due to litter decomposition [31].

The lowest contents in each sampling date appeared at SWA (205.34 mg/kg, August), SFC (237.59 mg/kg, September), and SWA (233.94 mg/kg, October) in subsurface soils, but not at those treatments for surface soils. Variability of TN contents in surface soils was higher than those in subsurface soils. This was because denitrification enzyme activities in upper soils were stronger than those in deeper soils [32].

At 5- and 10-cm water levels, TN contents steadily changed at the two soil layers. However, TN contents are generally higher than those in subsurface soils, which was due to plant uptake from subsurface soils and exogenous nitrogen (e.g., nitrogen deposition) input to surface soils [7]. TN contents in surface soils changed more quickly than those in subsurface soils when the soil was over-wetted. This was associated with an oxidation layer in the interface of water–soil under submerged conditions, since mineralization and subsequent nitrification can occur in this layer [33].

Correlation analysis between TN and NO$_3$–N contents was conducted for different soil layers (Tab. 1). TN contents showed weak negative correlation with NO$_3$–N contents for all soil layers ($p > 0.05$). This might be related to organic nitrogen mineralization and nitrification which can result in the increase in NO$_3$–N and the decrease in TN, since more than 95% of TN consists of organic nitrogen in wetland soil [34].

### 3.2 Effects of water level and salinity on TP contents in mash soils

Figure 4 shows the distribution characteristics of TP contents along different water levels and salinity gradients. As shown in Fig. 4, TP contents appeared an accumulation peak value in each sampling date at such treatments as SFC (751.16 mg/kg), FWA (722.39 mg/kg), and FWA (638.09 mg/kg) in surface soil. It also showed a decreasing tendency with increasing salinities. Similarly, TP contents in subsurface soils also showed a decrease with increasing salinities. This was consistent with the results reported by Lv et al. [35] in her study on the relationship between TP contents and salinities in wetland soils of the Yangtze River Delta. It was because the microbial activities might be inhibited at higher salinity levels [36]. However, this was not in agreement with the conclusion reported by Neill [37], that P was the limiting nutrient for wetland plants except for higher salinity sampling sites in Ireland.

Higher water level could contribute to TP accumulation in surface soils. However, the relationship between water level and TP content still remained unclear, and the results greatly varied in different regions. Tong et al. [38] had reported that there were significantly positive correlations between TP contents and water levels in the Minjiang River estuary. Dunne et al. [39] also found P release was significantly and negatively correlated with hydro-periods in wetlands.

As shown in Tab. 2, two-way ANOVA analysis of TP showed that there were significant differences between different water levels in subsurface soils ($p < 0.05$). Similar to TN, salinity treatments showed significant effects on TP contents in the top 20-cm soils ($p < 0.05$). This result suggested that salinity played an important role in soil nutrient change. This was likely related to the decomposition and accumulation of SOM under different environmental conditions. Bai et al. [40] also reported that TN and TP were closely related to SOM in wetland soils. In this study, significant differences in SOM contents in the top 20-cm soils were only observed among salinity levels ($p < 0.05$, Fig. 5). Moreover, the accumulation peaks of SOM contents were almost observed under higher salinity levels (such as FS or SF).

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>TN</th>
<th></th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil layer</td>
<td>0–10 cm</td>
<td>10–20 cm</td>
<td>0–20 cm</td>
</tr>
<tr>
<td>Water level</td>
<td>0.005</td>
<td>0.208</td>
<td>0.774</td>
</tr>
<tr>
<td>Salinity</td>
<td>0.949</td>
<td>0.530</td>
<td>0.016</td>
</tr>
<tr>
<td>Water level + salinity</td>
<td>0.197</td>
<td>0.432</td>
<td>0.471</td>
</tr>
</tbody>
</table>

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This was because it was different for SOM to be mineralized and decomposed under higher salinity and anaerobic condition [41] due to microorganism activities. Decomposition and mineralization were considered as the main outputs of SOM [42]. Thereby lower TN or TP contents were closely related to SOM contents under higher salinity condition.

4 Concluding remarks

This study demonstrated that TN and TP contents in the top 20-cm soils were significantly affected by salinity, which indicated a decreasing tendency with increasing salinities. The effects of water level on TN and TP contents were weaker compared to salinity. Nutrient contents in wetland soils were closely linked to SOM, and their changes with increasing water level and salinity treatments might be dominantly controlled by microorganism activities. However, further study concerning the complex mechanism is still needed. The findings of this study can provide a useful reference for further research regarding the effects of tidal flooding on soil nutrients in other coastal wetlands and can contribute to efficient restoration of degraded wetlands in coastal regions.

Acknowledgments

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The authors have declared no conflict of interest.

References


