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In situ soil net nitrogen mineralization in coastal salt marshes (*Suaeda salsa*) with different flooding periods in a Chinese estuary

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ABSTRACT

Flooding periods can be one of the most important factors influencing nitrogen (N) biogeochemical processes in wetlands ecosystem. We conducted a field study using *in situ* incubation method to investigate the seasonal dynamics of soil net N mineralization in three coastal salt marshes (*Suaeda salsa*) with different flooding periods (*i.e.*, short-term (STF), seasonal (SF), and tidal (TF) flooding wetland) in the Yellow River Delta. Selected soil inorganic N pools (ammonium, nitrate and inorganic N) and N transformation (mineralization, nitrification and ammonification) rates in the top 0–10 cm soils were repeatedly quantified from April to October. Clear seasonal patterns in inorganic N pools and transformation rates were observed in accord with the seasonal variations of temperature and moisture. Generally, higher levels of soil inorganic nitrogen, ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) occurred in the early-growing season (April), and NH_4^+-N contents got a small accumulative peak in midsummer (September). The lower rates (negative) of net mineralization (R_{min}), nitrification (R_{nit}) and ammonification (R_{amm}) were observed in the early-growing season (April–June) and fall (September–October), whereas higher values (positive) in midsummer (August–September). Flooding had a significant influence on inorganic N pools (except for NH_4^+-N) and transformation rates ($p < 0.05$). R_{min} values in SF wetland were significantly higher in the August-September period than those in other incubation periods. R_{nit} values in TF wetland exhibited a small variation and the highest value occured in the June–August period. The results of principal component analysis showed that soil samples were clearly divided into two groups before and after flow-sediment regulation. After flooding events, the R_{min} and R_{amm} values generally increased in the three wetlands, whereas a significant decrease in R_{nit} values was observed in SF wetland ($p < 0.05$), thus the differences in NO_3^--N among these wetlands were eliminated. These results suggested that seasonal variations in temperature and moisture are important factors influencing inorganic N pools and transformation rates.

1. Introduction

Coastal wetlands are the transitional zones between the terrestrial and marine ecosystems, which are characterized by high biodiversity, productivity and susceptibility (Mitsch and Gosselink, 2015), and the "sinks", "sources" and "transformations" of chemical elements (*i.e.*, nitrogen and phosphorous) (Flynn, 2008). Nitrogen often acts as a limiting nutrient for coastal salt marshes, and nitrogen availability is always considered to have considerable impacts on the structure and productivity of plant community (Mitsch and Gosselink, 2015). Nitrogen mineralization is the key process that converts organic nitrogen into inorganic N by soil microorganisms (Niedermeier and Robinson, 2007), which controls the N bioavailability for wetland plants and includes both ammonification and nitrification processes. Ammonification is the process in which organic matter is converted to ammonia by microorganisms. Meanwhile, the subsequent nitrification of NH_4^+-N can also influence N availability by controlling N loss (Groffman and Tiedje, 1989) or by changing the relative availability of NH_4^+-N and NO_3^--N since plants have different capabilities to assimilate inorganic N forms (Mendelssohn, 1979). Therefore, a better understanding of soil nitrogen mineralization in coastal salt marshes can contribute to improving soil fertility and quality management to maintain coastal wetland ecosystem health.

Nitrogen cycle, especially N mineralization and inorganic N pool, is sensitively impacted by wetland hydrology and environmental

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Table 1
In situ incubation periods in three wetlands.

Incubation period	April–June	June–August	August–September	September–October
date of incubation (2008)	4.26–6.7	6.7–8.9	8.9–9.11	9.11–10.14
days of incubation	42	32	34	33

factors (Gao et al., 2012). The frequent drying and wetting alternation will stimulate decomposition of soil organic matter (SOM) and increase inorganic N but exacerbated N losses (Birch, 1960; Sahrawat, 1980). Bai et al. (2005, 2007) presented that flooding duration and frequencies could influence soil nitrogen distributions, because drying and wetting cycles can greatly influence soil properties and soil oxic and anoxic periods (Neill, 1995), and then affect SOM decomposition and microbial activities (Turner and Patrick, 1968). Gao et al. (2012) observed that R_{min} increased and NO_3^--N decreased after freshwater flooding events due to the potential for anaerobic nutrient cycling promoted by flooding. Liu et al. (2012) showed higher levels of total nitrogen at 10 cm water level treatment in August and September, and at 0 cm water level in October in the Yellow River Delta. Salinity is another vital factor influencing N mineralization in coastal wetlands. Pathak and Rao (1998) suggested that increasing salinity will suppress N mineralization. However, Gao et al. (2014) demonstrated higher salinity promoted the N mineralization. Zeng et al. (2013) reported the increasing rates of nitrification with increasing salinity under a threshold. Temperature and moisture are often considered to be the two important factor influencing N mineralization (Grenon et al., 2004). In general, the sensitivity of nitrogen mineralization to temperature is maximal at 25 °C and the optimal moisture content is between 50% and 100% of field capacity (Guntiñas et al., 2012). Additionally, plants can affect N mineralization through nutrients uptake and competition with microbes for nutrients (Vitousek, 1982). However, little information is available on the combined influence of seasonal variation and flooding periods on soil inorganic N pools and net N mineralization, nitrification and ammonification rates of *Suaeda salsa* in coastal salt marshes.

Therefore, the primary objectives of this study were: (1) to investigate seasonal variations in soil inorganic nitrogen (NH_4^+-N and NO_3^--N) and *in situ* net nitrogen mineralization, nitrification and ammonification rates in salt marshes with different flooding periods in the Yellow River Delta; and (2) to identify the key factors influencing soil N pools and net nitrogen transformation rates.

2. Materials and methods

2.1. Site description

The study was conducted in *Suaeda salsa* salt marshes in the Yellow River Delta Nature Reserve (37°35′–38°12′N, 118°33′–119°20′E), Shandong province of China, during the period from April to October in 2008, which is an important transit point, wintering habitat and breeding grounds for bird migration in northeast Asia and west Pacific, and has been included in the Ramsar List of Wetlands of International Importance. The Yellow River Delta has a typical monsoon climate with an annual mean air temperature of 11.9 °C and 196 frostless days. The annual mean rainfall is 640 mm and mainly concentrates in summer (from June to August) and the annual mean evaporation is 1962 mm. The Fluvo-aquic soil and saline soil are the main soil types in the study area. The predominant vegetation includes *Suaeda salsa, Phragmites australis, Triarrhena sacchariflora and Tamarix chinensis*. *Suaeda salsa* (*Chenopodiaceae*) is a succulent halophytic herb (Wang et al., 2004), and generally germinates in late April, blooms in July, matures in late September, and completely perishes in November. Complex wetlands hydologcial condition were developed in the study area due to freshwater flooding caused by flow-sediment regulation and the irregular semidiurnal tide. Three *Suaeda salsa* wetlands with different flooding periods were selected in this study. Short-term flooding wetland (STF) can only be flooded for approximately one month after flow-sediment regulation, whereas seasonal flooding wetland (SF) can be flooded and last approximately three to four months, and the freshwater from the Yellow River is their main surface water source. Tidal flooding wetland (TF) can be flooded by tidal seawater twice one day.

2.2. In situ *incubation experimental design*

In situ incubation can reflect the natural state of the soil net nitrogen mineralization, nitrification and ammonification. In this study, we choose polyvinyl chloride (PVC) top-closed pipe *in situ* incubation method to ensure soil in the pipe had the same structure and temperature as the outside soil. Soil sampling plots with three replicates were randomly set in each of three flooding wetlands, and a total of nine sampling sites were assembled. The *in situ* incubation experiment lasted for four periods from April to November of 2008 (Table 1). At the beginning of each incubation period, three incubation tubes (25 cm in length and 5 cm in diameter) (tubes A, B, C) were inserted in each sampling plot after removing plant litter layer on the surface soil, with 10 cm left above away from the surface soil. The incubation tube A was removed immediately, and soil samples were collected for the determination of the initial values of NH_4^+-N, NO_3^--N and other soil properties, *e.g.*, soil SOM, salinity, soil total carbon (TC) and total nitrogen (TN), and the incubation tube B was remained for next 30–40 days incubation period in the field. The incubation tube C was stayed in the soil and sealed using a plastic breathable membrane on the top to ensure the soil aerobic respiration and prevent leaching. Meanwhile, another soil core (100 cm^3) in each sampling plot was collected to determine soil bulk density (BD) and water content (WC). At the end of each incubation period, the incubation tubes B and C were pulled out and the soil in the tubes were simultaneously collected for physical and chemical analysis. Then inserted another three new incubation tubes to achieve the purpose of continuous monitoring in the field.

2.3. Soil sample collection and analysis

All soil samples in the incubation tubes were placed in polyethylene bags and brought to the laboratory. Some fresh soils were sieved to remove the coarse debris and stones and used to determine the NH_4^+-N and NO_3^--N contents. Approximately 10 g (fresh mass) soil samples were extracted with 50 mL of 2 M KCl solution. Extracts were mixed for 1 h on the rotational shaker and conducted on an automated flow injection analysis AA3 (Bran + Luebbe, Germany) to determine soil NH_4^+-N and NO_3^--N contents. Soil inorganic nitrogen (SIN) was expressed as the sum of NH_4^+-N and NO_3^--N. The reminding soil samples were air-dried in the laboratory at room temperature for two or three weeks and ground through a 2-mm sieve to remove the coarse debris and stones for the determination of soil physical and chemical properties. Soil pH and salinity (SAL) were measured using a pH meter and salinity meter, respectively (soil/water, 1:5). SOM was determined using Walkley and Bland method (Walkley and Black, 1934). Soil BD and WC were determined by drying soil samples at 105 °C for 24 h in an oven.