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Short-term effects of tidal flooding on soil nitrogen mineralization in a Chinese tidal salt marsh

Haifeng Gao [a, *], Junhong Bai [b, *], Xiaoya Deng [c], Qiongqiong Lu [b], Xiaofei Ye [d]

[a] Key Laboratory of Tibetan Plateau Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101 China
[b] School of Environment, Beijing Normal University, State Key Joint Laboratory of Environmental Simulation and Pollution Control, Beijing 100875 China
[c] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038 China
[d] Railway Construction Headquarters, Transport for Housing and Construction, Zhenhai District, Ningbo City, Zhejiang Province 315200 China

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ABSTRACT

Tidal flooding is an important control of nitrogen biogeochemistry in wetland ecosystems of Yellow River Delta, China. Variations in hydrology could change soil redox dynamics and conditions for microorganisms living. A tidal simulation experiment was designed to extract tidal flooding effect on nitrogen mineralization of salt marsh soil. Inorganic nitrogen and relevant enzyme were measured during the 20-day incubation period. Considering the variation of both inorganic N and enzymes, nitrogen mineralization process in tidal salt marsh could be divided into 2 phases of short term response and longtime adaption by around 12th incubation day as the inflection point. Soil ammonium nitrogen (NH_4^+-N) and volatilized ammonia (NH_3) occupied the mineralization process since nitrate nitrogen (NO_3^--N) was not detected over whole incubation period. NH_4^+-N varied fluctuant and increased significantly after 12 day's incubation. Released NH_3 reached to peak value of 14.24 mg m^{-2} d^{-1} at the inflection point and declined thereafter. Inorganic nitrogen released according to net nitrogen mineralization rate (R_M) under the tidal flooding condition without plant uptake except first 2 days. However, during the transitional period of 6−12 days, R_M decreased notably to almost 0 and increased again after inflection point with the value of 0.182 mg kg^{-1} d^{-1}. It might be due to the change of microbial composition and function when soil shifted from oxic to anoxic, which were reflected by arylamidase, urease and fluorescein diacetate. Fluorescein diacetate hydrolysis and arylamidase had the similar variation of U style with decreasing activities before 12 days' incubation. All the enzymes measured in this experiment increased after inflection point. Whereas, urease activity kept constant from 2 to 12 days. Alternant oxidation reduction condition would increase N loss through denitrification and ammonia volatilization during the transitional period, while more inorganic nitrogen would be available in reductive environment of long-term tidal flooding. Therefore, hydrological process regulation has great influence on nitrogen cycling and further influence on wetland productivity.

1. Introduction

Coastal wetlands, located between ocean and terrestrial land, are complex ecosystems due to fresh water and sea water mixing, suspended matter and nutrient deposition and the changing anaerobic and aerobic condition (Bai et al., 2012). As the most limiting and essential nutrient in coastal wetlands (Moseman-Valtierra et al., 2009), soil available nitrogen greatly impacts wetland primary productivity and plant community structure (Mitsch and Gosselink, 2007). Nitrogen mineralization is a key biogeochemical process transforming organic N to inorganic N by heterotrophic microorganism and extracellular enzymes (Mishra et al., 2005; Luo et al., 2016), which primarily determines the N availability in estuarine and coastal soils. This process is sensitive to variation of wetland hydrology and environmental factors from climate change and intensifying human activity (Guntiñas et al., 2012; Gao et al., 2014; Lewis et al., 2014; Sherstha et al., 2014; Jia et al., 2017). A better understanding of N mineralization in

* Corresponding authors.
E-mail addresses: gaohf03@hotmail.com (H. Gao), junhongbai@163.com (J. Bai).

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complex environment can contribute to improving soil fertility and quality management to maintain coastal ecosystem health.

Variations in hydrology including soil inundation and moisture content change soil redox dynamics (Niedermeier and Robinson, 2007; Pal et al., 2010) and conditions for microorganisms living (Geisseler et al., 2011; Koschorreck and Darwich, 2003). Current evidence is inconsistent regarding how soil inundation and moisture content affect mineralization rates. Generally, increased inundation will exacerbate anoxia which has lower energy yields than oxic respiration, further suppress mineralization rates since soil organic matter is energetically favorable to mineralize (Canfield, 1993; Lewis et al., 2014). However, frequent drying and wetting alternation, flooding duration and frequencies will complicate this process (Bai et al., 2012; Kirwan et al., 2013; Sherstha et al., 2014).

We conducted in-situ incubation to investigate how soil nitrogen mineralization respond to soil inundation of coastal wetland ecosystems (Gao et al., 2012a). Three *Phragmites australis* wetlands with different flooding periods were selected. Tidal flooding wetland can be flooded by tidal seawater twice one day, while short-term flooding and seasonal flooding wetlands can be flooded by freshwater from Yellow River after flow-sediment regulation for approximately one month and three to four months, respectively. The study discovered nitrogen mineralization in tidal flooding wetland was quite unique with relative constant mineralization rate in comparison with other two flooding type wetlands. Soil inorganic N contents and microbial activities in tidal salt marsh increased during inundation period of flow-sediment regulation, which was opposite with the reaction of other two wetlands. Physical (sediment transport, tidal pumping, wave action, bioturbation), chemical (oxidation-reduction, precipitation-dissolution, adsorption), and microbial processes regulate the cycling of nitrogen in tidal salt marshes together (Taillefert et al., 2007). It is difficult to determine that the unique phenomenon is caused by either nitrogen input or hydrology and salinity regime. Meanwhile, climate change possibly increases soil inundation owing to sea level rise, results in more altitude region been dominated by tidal flooding.

We therefore design a simulation device to extract the only tidal flooding effect on process of nitrogen mineralization in tidal flooding salt marsh. This was achieved by tidal simulated incubation with undisturbed soil pillar from where in situ experiment was manipulated (Gao et al., 2012a). This approach of measuring inorganic nitrogen and relevant enzyme provides reasonable insight into tide influence on nitrogen transformation process of tidal flooding salt marsh.

2. Methods

2.1. Site description

The Yellow River Delta is one of the most active regions of land-ocean interaction among the large river deltas in the world. Large amount of sediment is carried by the Yellow River and deposited at the estuary to form new land. It has typical monsoon climate of warm temperate zone, with the annual mean air temperature of 11.9 °C and 196 frostless days, annual mean precipitation of 640 mm and approximately 70% of rainfall is mainly allocated in summer (from June to August) (Gao et al., 2012a), annual mean evaporation of 1962 mm and drought index of 3.56 (Cui et al., 2009). The study area (37°35′-38°12′ N, 118°33′-119°20′ E) is located in the estuary of the Yellow River Delta Nature Reserve in Shandong Province, China. There are three main *Phragmites australis* wetlands with different flooding frequencies (Gao et al., 2012a). Tidal flooding salt marsh is located at the lower-terrain place near the beach with tidal currents as the major factors controlling the wetland evolution, which could be submerged and ebbed by sea water with semi-diurnal tidal variation every day. The soil properties of tidal salt marsh before incubation are shown as following in Table 1. Alluvial soil is the dominate soil types in this typical wetland area. It is a C-poor costal salt marsh with low C:N and high salinity.

2.2. Experimental design and chemical analysis

2.2.1. Sampling

Intact soil cores were collected in the typical flooding wetland of Yellow River Delta. The plants of *Phragmites australis* were cut carefully before soil collected. Soil cores were taken by 5 cm diameter polyvinyl chloride tubes to a depth of approximately 15 cm, sealed at the bottom with gas-and water-tight end caps, and transported to the laboratory with 4 °C temperature. To reduce the difference among soil samples, sampling tubes were ranged as tightly as possible in the quadrat.

2.2.2. Incubation

Inundation situation was considered to reflect the tidal effect in designed experiment. Intact soil cores were put into the incubation tubes. As the duplicate, every two tubes composed one group randomly, connected by hosepipe near the surface of the soil pillar. Then 35‰ NaCl solution, equivalent to sea water concentration, was added up to 10 cm depth above soil surface. After pre-incubation for one day under 25 °C in the dark, one of two incubation pipe was raised to make the salt solution flow to the other side through hosepipe. The valve on hosepipe was turned off till the water level dropped to the soil surface for one side (low tide). The inundated counterpart was now submerged as same as high tide situation. The same process was operated to shift flooding condition of two tubes after every 12 h. The flow from one tube to the other was controlled slowly by valve, to prevent disturbing the soil. There were in total 4 groups soil pillars with same process. After 2, 6, 12, 20 days, soil samples in each incubated group were collected to analysis.

2.2.3. Ammonia volatilization measurement

Additionally, ammonia volatilization was measured by semi-opened chamber methods modified according to Gao et al. (2012b) during the period of simulated incubation. Two polyethylene foam discs of 1 cm thick and 6 cm diameter were placed into the top of incubation pipe. The foams were soaked with approximately 2 mL of a solution of phosphoric acid (50 mL L^{-1}) and glycerin (40 mL L^{-1}). The first disc, placed near the mouth of incubation pipe, absorbs the NH_3-N volatilized from soil. The second disc, placed 2 cm from the first, protects the first disc from the ammonia from the atmosphere. The foam discs were periodically collected every 12 h and set every 2 days. The collected foam discs were kept in each sealed container at 4 °C before analysis within one week.

2.2.4. Enzymes index selection

As the main participants of soil organic matter transformation and circulation, soil microorganisms and enzymes play an important role in nitrogen cycling of ecosystems (Lin, 2010). Nitrogenous organic compounds in soil have converted to the form which can be absorbed by plant after a complex bio-chemical conversion. Soil enzymes are obligated participation in each phase of the nitrogen transformation. Arylamidase is a typical peptidase, which can catalyze the hydrolysis of an *N*-terminal amino acid from peptides, amides, or arylamides (Acosta-Martinez and Tabatabai, 2000; Dodor and Tabatabai, 2007). The release of amino acids is the first