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Vertical migration and distribution of added dissolved iron in *Carex lasiocarpa* marsh soil

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ABSTRACT

Irrigating rice paddy fields with groundwater containing iron is standard practice for dry croplands replanted to rice in northeast China. To assess the impact of paddy field drainage on the receiving natural wetlands, vertical migration and distribution of dissolved iron in the soil–plant system with acidic dissolved iron addition were investigated in the *Carex lasiocarpa* marsh soil columns (diameter 35 cm, height 65 cm) of the Sanjiang Plain. The experiment was designed as four sequential stages: (1) iron-free leaching, (2) neutral iron addition using $FeSO_4$ (100 mg L^{-1} of iron concentration), (3) acidic iron addition using $FeSO_4$ and HCl (200 mg L^{-1} of iron concentration, pH adjusted to 3.56) and (4) iron-free leaching. After the experiment, the iron distribution within a natural wetland ecosystem was quantitatively observed. The results showed that pH and Eh in the soil columns were affected more by water table fluctuations than acidic addition. Effects of iron addition on the dissolved iron in soil solutions decreased with increasing soil depth, and the vertical migration rates in 20–30 cm layer (AG horizon) and 30–50 cm layer (G horizon) were 0.58 and 0.56 mm min^{-1}, respectively. Doubling the iron addition did not increase the iron in soil solutions significantly. Only a small part of added iron (5.7%) drained out, while the majority was retained in soil (69.4%) and plant biomass (24.8%). Soil manganese and nitrogen were positively affected by acidic iron addition, while the effects on carbon and phosphorus were not significant.

1. Introduction

Iron plays important roles in wetland biogeochemistry. Although the mobility of iron is low in upland ecosystems, migration of dissolved iron (which can pass through 0.45-μm membrane filter) occurs under anaerobic conditions in wetlands (Poulton and Raiswell, 2002). Mechanisms involved in iron migration in wetlands include a series of biotic and abiotic reactions, such as redox, deposition, adsorption, co-precipitation, microbial utilization, and plant uptake (Matagi et al., 1998; Johnson and Hallberg, 2005; Sheoran and Sheoran, 2006). For some of these processes coexist, the actual migration flux of dissolved iron is difficult to be described or calculated. However, when iron migration is treated as "black box", the actual flux can be modeled as the function of wetland hydrology, hydraulic retention time, pollutant load, pH, Eh and other parameters (Flanagan et al., 1994; Ye et al., 2001; Batty et al., 2008; Kröpfelová et al., 2009; Zou et al., 2011a).

Beside the natural influencing factors, some anthropogenic activities (e.g. land conversion and canalization for agriculture) affect iron migration through changing the hydrological regime and pH–Eh conditions in wetlands as well (Zou et al., 2011b), which increase the complexity of iron migration in these areas. Therefore, more comprehensive studies on the coupled natural and anthropogenic effects on iron migration are needed to further understand the iron biogeochemical processes in the wetlands under the pressure of changing environment.

Since the 1950s, agricultural conversion of freshwater marshes in Sanjiang Plain, one of the most important crop production bases in China, has significantly changed the regional wetland ecosystem. A significant quantity of groundwater has been used to irrigate rice paddies since the 1990s (Zhao, 2009). High concentrations of dissolved iron have been observed in the groundwater (Wang et al., 1997, 2004; Pan et al., 2007), with average values ranging from 3.53 mg L^{-1} to 5.48 mg L^{-1}. As a consequence, considerable dissolved iron is transferred from groundwater to surface water bodies. The iron is partly precipitated in paddy soils and drainage canals, while some migrates through surface water into natural wetlands and Heilongjiang (Amur) River (Onishi et al., 2008). The impact to downstream wetlands of irrigating rice paddy fields with iron-rich groundwater has not been documented.

A typical natural wetland type in Sanjiang Plain is the *Carex lasiocarpa* marsh. It is low-lying areas and can collect agricultural

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drainage. In this study, we observed the vertical migration of added dissolved iron in three soil columns collected from a *C. lasiocarpa* marsh to assess the impact of acidic and iron-rich paddy field drainage on natural marsh wetlands downstream. The dynamics of dissolved iron migration during simulated acidic agricultural drainage were observed through measuring the dissolved iron concentrations in each soil layer for 16 times. The iron distribution within the marsh plants and soil columns after acidic iron addition were tested and calculated. In order to represent the worst case scenario, high levels of iron and proton concentrations (low pH) were manipulated in the experiment. Although so great concentrations were impractical, this hypothetically simulated scenarios would provide a beneficial perspective on iron migration in natural wetlands affected by agricultural drainage and pollutant levels in wetland ecosystems after receiving extremely acidic iron drainage.

2. Materials and methods

2.1. Study site description

The tested soils were collected in situ from *C. lasiocarpa* wetland (47°35′07″N, 133°29′58″E) in the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Sciences, which represents the typical landscape of the Sanjiang Plain Wetland of northeast China. The annual mean precipitation is 550–600 mm and the annual mean temperature is approximately 1.9 °C (−21 and 22 °C). *C. lasiocarpa* is one of the dominant plants in this area, and peat marsh soil has developed herein. The specific description of the soil is listed in Table 1.

2.2. Design of simulated soil columns

Three replicated soil sites were randomly chosen from a natural *C. lasiocarpa* wetland. The plant litters above each soil site were removed with a sickle, and each soil column was collected according to the distinct soil horizon in June prior to soil thawing and plant growth. The soils were filled into three polyethylene buckets (diameter 35 cm, height 65 cm, bottom valve attached) one layer after another. Because the depth of each filled layer was only a half of the original horizon depth, the actual height of the simulated soil column is 50 cm. Soil solution extractors were installed within each soil layer (Fig. 1). Each soil solution extractor was composed of a plastic tube and porous ceramic filter with a pore size of 0.2–0.5 μm. This device utilized negative pressure to extract the soil solution in vacuum tubes through a porous filter. Iron passing this pore size was considered to be in dissolved form, and the total iron concentration (TFe) was the sum of Fe(II) and Fe(III) (Zou et al., 2009a; Yu et al., 2011). In order to simulate the natural soil conditions, each column was placed in a 50-cm depth hole within the wetland where the soil columns were collected, so that these soil columns were flush with the wetland surface water to maintain ambient moisture and temperature for 14 months, and to restore and develop the soil structure and vegetation.

2.3. Observation of dissolved iron migration

The dissolved iron migration experiment was carried out in August of the following year (year) when biomass reached its peak. In order to collect the leachates from the bottoms of the buckets, the columns were taken out from the wetland and then placed on the ground nearby during the sequential leaching. Prior to initiation of the experiment, all columns were drained completely through the bottom valve to remove dissolved iron. Then the valves were closed and four sequential stages of the vertical migration experiment were carried out as follows.

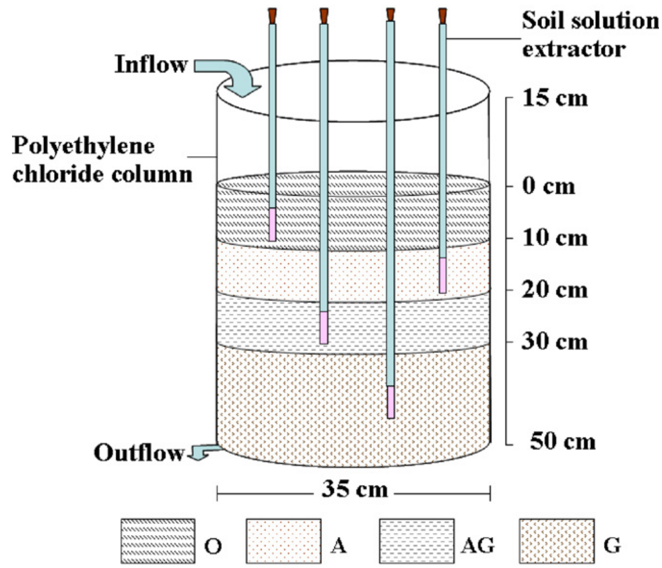

Fig. 1. Design of the experimental soil column. The device contains polyethylene chloride bucket and soil solution extractors that use negative pressure to extract the soil solution in vacuum tubes through a porous ceramic filter with pore size of 0.2–0.5 μm. Iron passing this pore size is considered to be in dissolved form.

Stage 1: iron-free leaching. Deionized water was manually dosed onto the top of each column until the column maintained 10-cm depth of surface water. Two hours later when the vertical flow became balanced, each extractor was pumped to create a vacuum with a manual vacuum pump. After 10 min, each soil solution was collected in each plastic tube using a 50-ml plastic syringe through a long plastic straw. Then the bottom valve was opened to drain the column maintained 5-cm depth of surface water, the leachate was collected and the time-consumed during leaching was recorded. Soil solutions at this time were collected using a manual vacuum pump and a plastic syringe once more. After solution collection, the column was drained again until no surface water remained, the leachate was collected, the time-consumed during leaching was recorded, and the soil solutions were collected for the third time. Finally, the valve was opened and the column was allowed to drain completely. The leachate was collected, the time-consumed during leaching was recorded, and the soil solution was collected for the fourth time.

The vertical flow duration physically finished within the time-consumed for water table balance (2 h) and sampling (10 min), but processes that added dissolved iron interacts with soil and soil solution may just get started because those processes occur at a low rate. In fact, the chemical processes did occur during the whole stage after dissolved iron manually dosed onto the top of each column. The actual interaction duration of iron added with soil column should add the leaching duration that was about 2 h, 4 h and 9 h from 10-cm depth of surface water to be drained to 5-cm depth, from 5-cm depth to 0-cm depth, and from 0-cm depth to be drained completely, respectively. The total contact duration of stage 1 was about 24 h consequently. According to our previous study of iron retention in *C. lasiocarpa* marsh (Zou et al., 2011a), the iron retention efficiency within 24 h was over 90%. Therefore, the interaction of iron added and soil column would be chemically adequate during stage 1.

Stage 2: low-iron-concentration and neutral-condition. This treatment was designed to observe the effect of iron addition. $FeSO_4$ solution (100 mg L^{-1} of TFe, pH was adjusted to neutral with NaOH solution) was manually dosed onto the top of the columns. The same procedure was conducted as described in Stage 1.