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RESEARCH PAPER

Biogeochemical cycle of Sulfer in the *Calamagrostis angustifolia* wetland ecosystem in the Sanjiang Plain, China

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Abstract: To better understand the Sulfur (S) cycle in the wetland ecosystem, the S cycle and its compartmental distribution within an atmosphere-plant-soil system were studied using a compartment model in the *Calamagrostis angustifolia* wetland in the Sanjiang Plain, Northeast China. The results showed that the soil was the main S storage and flux hinge in which 97.78% S was accumulated. In the plant subsystem, the root was the main S storage, and it remained at 79.60% of the total S contents, which in the *Calamagrostis angustifolia* wetland ecosystem showed that the parts above the ground took up 0.75 g S/m^2, the S re-transferring biomass to the root was 0.24 g S/m^2, and to the litter was 0.51 g S/m^2; the root took up 3.76 g S/m^2 and the S transferring biomass to the soil took up 3.07 g S/m^2; the litter S biomass was 0.75 g S/(m^2·a) and the S transferring biomass to the soil was more than 0.52 g S/(m^2·a). The emission amount of H_2S from the *Calamagrostis angustifolia* wetland ecosystem to the atmosphere was 1.42 mg S/m^2, whereas carbonyl sulfide (COS) was absorbed by the *Calamagrostis angustifolia* wetland from the atmosphere and the absorption amount was 1.83 mg S/m^2. The S input biomass from the rain to the ecosystem was 4.85mg S/m^2 during the growing season. The difference between input and output amounts was 5.26 mg S/m^2, which indicated that S was accumulated in the ecosystem and would lead to wetland acidification in the future.

Key Words: Sanjiang Plain; *Calamagrostis angustifolia* wetland; ecosystem; sulfur; biogeochemical cycle

The wetland is a particular ecosystem that has multiple functions, and the study of nutrient cycling within a wetland ecosystem is the main interest of study in contemporary ecology[1]. S which is the fourth important nutrient after nitrogen, phosphor and kalium plays an important role in the growth process of plants, such as participation in composition of protein and aminophenol, photosynthesis, respiration and so on. Meanwhile S plays an important role in maintaining a healthy ecosystem. If the plant system lacks S, it will decompensate, stunt and finally die. The biogeochemical S processes in the wetland ecosystem have attracted wide attention[5–9] because they play an important role and are responsible for a series of important processes in the wetland ecosystem, such as carbon mineralization, water acidification, pyrite formation, tantalum cycling and so on[2–5]. However, except the study on the S cycle in soil-plant system[10], there has been comparatively little study on the S cycle in the wetlands of China; Zhang once reported the S accumulation and cycling in a mangrove ecosystem.

The Sanjiang Plain is one of the biggest regions in China, where all kinds of wetland types are widely distributed, and the marsh meadow and marsh are the main wetland types. The *Calamagrostis angustifolia* wetland, which takes up 34.45% of the total wetland area in Sanjiang Plain, Northeast China, is a large marsh meadow. The *Calamagrostis angustifolia* wetland is located at different water gradients; the redox changes intensively, affecting the S forms and translation in soil. However, to date, the information about the S cycle in the *Calamagrostis angustifolia* wetland is still limited; only Hao *et al.* have reported on the distribution of S in the *Calamagrostis angustifolia* wetland in the Sanjiang Plain, Northeast China[12]. To enrich and perfect investigation on the S cycle of

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the wetland ecosystem in the Sanjiang Plain, the *Calamagrostis angustifolia* wetland was selected as the research site in this article, and the distribution, accumulation, transformation and return of S to the wetland ecosystem were studied. Finally, the S cycling compartment model of atmosphere-plant-soil system was established and the status of S balance was evaluated.

1 Materials and methods

1.1 Site description

The experimental site is located at the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Sciences (47°35′N, 133°31′E) in Tongjiang City of Heilongjiang Province, China. The elevation of the study area is about 55.4–57.9 m with a gradient of 1:5000. The lowest, highest and annual mean air temperatures are −18 to −21℃, 21–22℃ and 1.6–1.9℃, respectively. The freezing period is up to five months and the nadir is 190 cm below ground. The average annual precipitation is 565−600 mm, of which more than 60% takes place from June to August. The dishing marsh is typical of the Sanjiang Plain marsh ecosystem, which is dominated in turn by *Carex pseudocuraica*, *C. lasiocarpa, C. angustifolia* and *C. angustifolia-Shrub* from the center to margins. The communities belong to the perennially flooded (7–25 cm), perennially flooded (0–10 cm), seasonally flooded (–8 to 5 cm) and non-flooded zones, respectively. The soil at the sites is of peat marsh, humus marsh and meadow marsh.

1.2 Sampling and study methods

The biomass above the ground and the standing litter biomass were collected using the harvest method every half a month from May to September 2005, and the biomass below the ground was collected using the digging method. Size of each plot was 50 cm × 50 cm. Litter decomposition was studied using litterbags made of nylon (0.5 mm × 0.5 mm mesh) with an inside area of 20 cm × 20 cm from May 2004 to September 2005. All the samples were collected triply.

Plant S storage (S_n) and S flux between plant compartments (F_a) were calculated by the following formula[13]

$$S_n = C_n B_n \quad (1)$$

$$F_a = C_a B_a \quad (2)$$

Standing litter S storage (F_{da}), S retransferring biomass from above the ground to the root (F_{rt}), and root uptake S biomass (F_r) were calculated by Equs. 3 – 5:

$$F_{da} = C_d B_a \quad (3)$$

$$F_{rt} = F_a - F_{da} \quad (4)$$

$$F_r = F_a - F_{rt} + \Delta S_u \quad (5)$$

where C_d is the S concentration in dead plants above the ground; B_a is the maximum biomass above the ground; ΔS_u is the net biomass increment below the ground in the growing season.

Steady litter biomass (X_{st}) and litter weight losing rate (R) were calculated by Equs. 6–7[15]:

$$X_{st} = x/(1-e^{-k}) \quad (6)$$

$$R = [(W_1-W_2)/W_1]\times 100\% \quad (7)$$

where e^{-k} is the litter remaining rate (%); W_1 and W_2 are litter weights (g) for the times t_1 and t_2 (d), respectively.

The S transferring biomass from litter to soil (F_s) and from root to soil (F_T) were calculated by Equs. 8 – 10:

$$F_s = F_l - F_y \quad (8)$$

$$F_T = T\cdot B_{max}\cdot C_{max} \quad (9)$$

$$T = P_m/B_{max} \quad (10)$$

where F_l is composed of F_{da} and F_p, where F_p is the S storage in the undecomposed litter; F_y is the S storage in the decomposed litter; T is the root turnover rate[14]; P_m is the difference of the root maximum biomass and the root minimum biomass; B_{max} is the root maximum biomass; C_{max} is the S content in root maximum biomass.

Soil samples were also collected using stainless steel corer per month from May to September 2005, the sampling depth was 60 cm, which was divided into 0–10 cm, 10–20 cm, 20–40 cm and 40–60 cm, and the soil unit weight was measured at the same time. The soil S storage was calculated using the following formula[16]. All the samples were collected triply. The main soil properties are listed in Table 1.

$$S_n = C_n \times V \times S_v \quad (11)$$

where C_n is the soil S content, V is the soil volume, and S_v is the soil unit weight.

The atmosphere precipitation was collected from May 2005 to September 2005, and the S sedimentation biomass was calculated by Equa. 12[17].

S sedimentation biomass (gS.m^{-2}) =

$$\sum [C_i \times 10^{-6} \times V_i)/A] \times 1000 \quad (12)$$

where C_i is the SO_4^{2-} concentration (mg/L), V_i is the precipitation volume (L), and A is the cross sectional area of the collector (0.0314 m^2).

The emission flux of S gases at each site was collected using the closed chamber[18]. The concentrations of H_2S and COS were determined as described in detail by Li *et al*.[19] and the emission flux was calculated using the following formula

$$F = \frac{MPT_0H}{V_0P_0T}\frac{dc}{dt} \quad (13)$$

where F is the gas emission flux (μg/(m^2·h)); M is the gas

Table 1 Properties of the tested soil

Soil layer	Organic matter(%)	Total S(mg/kg)	Total nitrogen(mg/kg)	Porosity(%)	pH
0–20cm	24.41	1112.97	9540.32	85.41	5.57