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Distribution characteristics of dissolved organic carbon in annular wetland soil-water solutions through soil profiles in the Sanjiang Plain, Northeast China

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Abstract

Overwhelming evidence reveals that concentrations of dissolved organic carbon (DOC) have increased in streams which brings negative environmental impacts. DOC in stream flow is mainly originated from soil-water solutions of watershed. Wetlands prove to be the most sensitive areas as an important DOC reserve between terrestrial and fluvial biogeosystems. This reported study was focused on the distribution characteristics and the controlling factors of DOC in soil-water solutions of annular wetland, i.e., a dishing wetland and a forest wetland together, in the Sanjiang Plain, Northeast China. The results indicate that DOC concentrations in soil-water solutions decreased and then increased with increasing soil depth in the annular wetland. In the upper soil layers of 0–10 cm and 10–20 cm, DOC concentrations in soil-water solutions linearly increased from edge to center of the annular wetland (R^2 = 0.3122 and R^2 = 0.443). The distribution variations were intimately linked to DOC production and utilization and DOC transport processes in annular wetland soil-water solutions. The concentrations of total organic carbon (TOC), total carbon (TC) and Fe(II), DOC mobility and continuous vertical and lateral flow affected the distribution variations of DOC in soil-water solutions. The correlation coefficients between DOC concentrations and TOC, TC and Fe(II) were 0.974, 0.813 and 0.753 respectively. These distribution characteristics suggested a systematic response of the distribution variations of DOC in annular wetland soil-water solutions to the geometry of closed depressions on a scale of small catchments. However, the DOC in soil pore water of the annular wetland may be the potential source of DOC to stream flow on watershed scale. These observations also implied the fragmentation of wetland landscape could bring the spatial-temporal variations of DOC distribution and exports, which would bring negative environmental impacts in watersheds of the Sanjiang Plain.

Key words: dissolved organic carbon (DOC); distribution characteristics; annular wetland; soil-water solutions; Sanjiang Plain

Introduction

The term dissolved organic carbon (DOC) is defined as comprising any organic carbon passing through a 0.45-μm filter and the entire pool of water soluble organic carbon either absorbed on soil or sediment particles or dissolved in soil interstitial water (Boyer *et al*., 1997; Evans *et al*., 2005). DOC is an important component of the carbon cycle and energy balance in streams (Tao and Lin, 2000). The transportation of DOC in rivers from terrestrial to marine environments constitutes a significant link in the global carbon cycle (Sachse *et al*., 2005; Wallage *et al*., 2006). Besides its contribution to the global carbon cycle, DOC interacts extensively with other dissolved substances (trace metals in particular) and affects contaminant transport.

Overwhelming evidence reveals that DOC concentrations have increased in recent years across the UK upland surface waters and in other locations including Europe and North America. Long-term DOC increase may have wide-ranging impact on freshwater biota, drinking water quality, coastal marine ecosystems and upland carbon balances (Eatherall *et al*., 2000; Worrall F *et al*., 2004, 2006; Thoms *et al*., 2005). Soils and vegetation of wetlands are important sources to a stream of allochthonous DOC. In a number of studies (Xenopoulos *et al*., 2003) positive spatial relationships have been demonstrated between DOC export and percentage of catchment area covered with peat. Those increases in DOC concentrations are associated with the variation of the peatlands which carbon-rich soils are a principal source of DOC to the fluvial environment. Consequently, peatlands prove to be most sensitive areas for DOC as an important DOC reserve and riparian wetland between terrestrial and fluvial biogeosystems which has received more attentions (Neal *et al*., 2005; Sommer, 2006). However, depressional wetlands were ignored due to the geometry of closed depressions, which have the phenomenon of internal drainage and are missing surficial outflows (John, 2001). Dishing wetland is the simplest

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wetland type with the same shape as depressional wetlands in the Sanjiang Plain.

The main aim of this research was to determine the distribution characteristics of DOC in annular wetland soil-water solutions. Annular wetland is a combination of dishing wetland and a forest wetland. In order to investigate the controlling factors of distribution variations of DOC in soil-water solutions through soil profiles, we conducted correlation analyses between DOC and other elements and as well as the DOC mobility.

1 Materials and methods

1.1 Study area

The Sanjiang Plain region, a winter-cold Zone in the Northeast China, is an alluvial plain deposited by the three major rivers of Heilong, Songhua, and Wusuli. Low slope grade and suitable climate conditions make it the largest mire wetland concentration in the entire China. Annular wetland occupies upper floodplain section, usually under water with infrequent substantial flooding. Annular wetland in the Sanjiang Plain receives water inputs only by the precipitation. Annular wetlands are the most prevalent wetland types with ring–shaped structure and high species richness. In history, this area was a contiguous wetland, but now the wetlands are fragmented into different hydrological units by a system of canals and levees (Liu and Ma, 2000; Liu *et al*., 2005). Accordingly, the fragmentation disturbance resulted in the conversion of the former annular wetlands from connected one with a temporary surface water or near-surface water connection to an adjacent upgradient wetland to the "isolated" wetlands.

The study site was located at approximately 47°35′31″E within the Sanjiang Mire Wetland Experimental Station, a field facility owned by the Chinese Academy of Sciences. A sampling transect was chosen from a forest wetland to the center of the adjacent dishing wetland at the Sanjiang Mire Wetland Experimental Station (Fig.1).

The forest wetland component of annular wetland is dominated by the plant communities of *Ass. Quercus mongolica* Fisch. ex Turez.-*Betula platyphylla* Suk. (a). The dishing wetland component is dominated by *Ass. Salix brachypoda* Trautv. et. Mey.-*Salix myrtilloides* L. -*Calamagrostics angustifolia* Kom. (b), *Ass. Carex lasiocarpa* Ehrh.-*Glyceria spiculasa* (Fr. Schmidt) Rosh. (c),

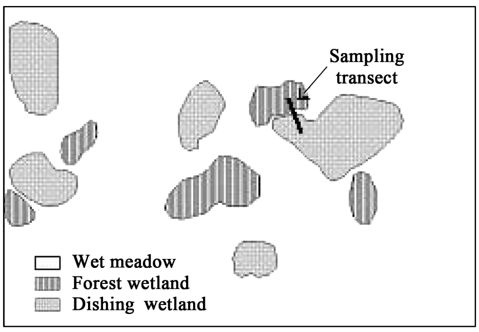

Fig. 1 Sketch map of the sampling transect.

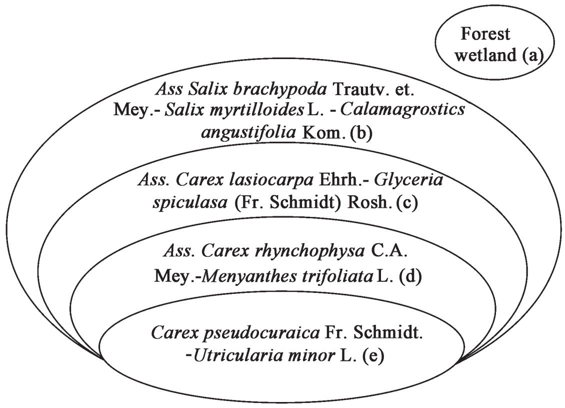

Fig. 2 Sketch map of ring-shaped structure of vegetation in the annular wetland. (a) Ass. *Quercus mongolic* Fisch. ex Turez. -*Betula platyphylla* Suk.

Ass. Carex rhynchophysa C.A.Mey.-*Menyanthes trifoliata* L. (d), and *Carex pseudocuraica* Fr. Schmidt. -*Utricularia minor* L. (e) (Fig.2). The annular wetland is characterized by poorly drained conditions that the development of redoximorphic features, gleying, organic matter accumulation, and minimal development of subsurface horizons. Soils in the annular wetland include peat soils, sphagnum-bog soils, gleization-bog soils, marsh podzol soils and baijiang soils with water gradients from less to more. This sampling transect extended from forest wetland to the joining dishing wetland across five vegetation strips (a–e).

1.2 Soil-water solutions collection

Water samples for this study were collected in June of 2006 along the sampling transect in the annular wetland. Water was extracted from soils at depth of 0–10, 10–20, 20–40, 40–60 and 60–80 cm from plant communities "a" to "e". Two water samples were collected and placed in the 50 ml glass vials. Several drops of hydrochloric acid solutions were added to one sample and transported to the laboratory in an ice bag. Another sample was directly transported to the laboratory in an ice bag. Samples were then analyzed for DOC, TOC (total organic carbon), TC (total carbon), and pH, TP (total phosphorus), TN (total nitrogen), Fe(II) and Fe(III). Three replicates were sampled at each site. Because of constraints from water samples, these analyses could not be performed on all the sites or soil profiles.

1.3 Chemical methods

The sample water was filtered through a 0.45-μm filter into separate vials for DOC analysis. The extracts were analyzed for DOC using high temperature combustion (total organic C-VCPH C analyzer, Shimadzu, Kyoto, Japan). The sample water was directly used for TOC analyses by the above method. All the chemical analyses were performed at the Key Laboratory of Wetlands Ecology and Environment, Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences.

The pictorial diagrams of the distribution variables of DOC in annular wetland soil-water solutions through soil profiles were performed by using origin 10.0. The Pearson correlation coefficients between two variables (DOC and other elements) were calculated by using SPSS 11.0 to find the main factors that affected the distribution characteristics of DOC in annular wetland soil-water solutions. In order to investigate the controlling factors of distribution variations of DOC in soil-water solutions through soil profiles, an investigation of DOC mobility was also made. Unless noted otherwise, statistical significance was determined at the 95% level.

2 Results and discussion

2.1 Distribution variations of dissolved organic carbon

Vertical variations of DOC in soil-water solutions through soil profiles from plant communities “a” to “e” were displayed (Fig.3). Significant high DOC concentrations in soil-water solutions mainly occurred in the topsoil (0–20 cm) of the annular wetland and the differences were not obvious from “a” to “e”. However, at site “c”, the DOC concentrations were the highest in soil-water solutions at depth between 60–80 cm. The DOC concentrations of the annular wetland soil-water solutions decreased and then increased with increasing soil depth and the lowest value of the DOC concentrations appeared at depth of 40–60 cm. However, at site “a”, the DOC concentrations in soil-water solutions with increasing soil depths followed the following order: 0–10 cm > 40–60 cm > 10–20 cm > 20–40 cm > 60–80 cm and the lowest value of the DOC concentrations appeared at depth of 60–80 cm.

Concentrations of DOC are typically the highest in the interstitial water of the carbon-rich upper soil horizons because DOC is leached from plants and is provided by decomposition and leaching of plants and soil organic matter within the soil profiles (Thurman, 1985). DOC concentrations decrease with depth as the amount of organic matter from plants decreases with a local minimum at depth of 20–40 cm and 40–60 cm in annular wetland soil-water solutions, which is consistent with the study of mineral soils (Sommer, 2002).

In the upper soil (10–20 cm and 20–40 cm), the differences of the DOC concentrations in annular wetland soil-water solutions were obvious at all sites and DOC concentrations linearly increased from “a” to “e” (Fig.4). Since geomorphic redistribution of carbon (C) can exceed plant C inputs to the soil profile (Yoo *et al*., 2001), we hypothesized that DOC fluxes of C could be an important C redistribution mechanism at the landscape scale. In our study, variation in soils, hydrology, and vegetation from “a” to “e” coincided with the topographic gradients of annular wetland. The DOC flux could link upslope wetlands to downslope dishing wetlands (Hartshorn *et al*., 2001). Sampling location of “a” was located relatively close to higher elevations, with high DOC brought from forest wetlands to lower elevation sites “b” to “e” by lateral flow in dishing wetlands. Accordingly, the highest value existed in the center of the annular wetland where runoff was low. The distribution variations indicated that DOC concentrations in organic soil pore waters were sequential and DOC was mobile in the annular wetland. In addition, from “a” to “e”, the distribution variations in annular wetland were linked to the correlations between DOC and other elements in soil-water solutions and DOC mobility. A correlation analysis and an investigation of DOC mobility followed are needed in annular wetland soil-water solutions.

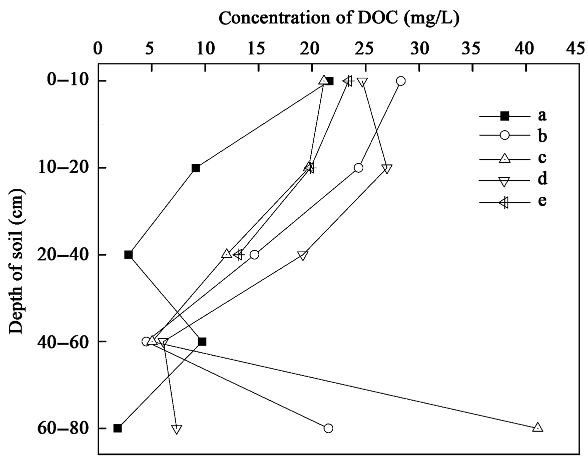

Fig. 3 Vertical variations of DOC in soil-water solutions through soil profiles from “a” to “e”.

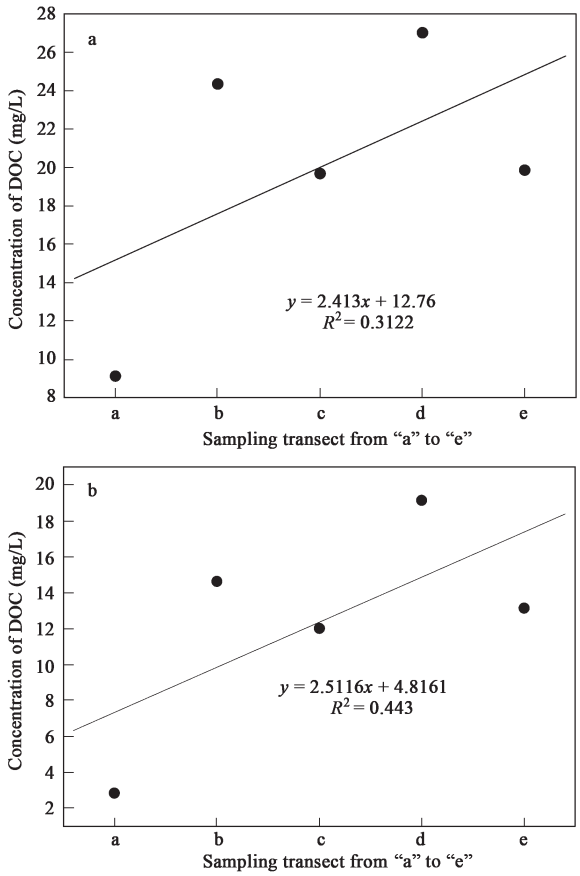

Fig. 4 A fit map of horizontal variations of DOC in annular wetland soil-water solutions from “a” to “e”. (a) horizontal variations of DOC in soil pore water at depth of 10–20 cm; (b) horizontal variations of DOC in soil pore water at depth of 20–40 cm.

2.2 Correlations analysis of DOC in soil-water solutions

Recently, DOC concentrations and its relationships to other elements in soil-water solutions have received more attentions. The strong relationship between DOC and Fe has been confirmed in several studies on matter export from forested biogeosystems. Compared to DOC, Fe budgets are two orders of magnitude lower. Nevertheless, catchments which are source areas for DOC are source areas for Fe as well (Sommer, 2006).

In the annular wetland soil-water solutions, the analysis of the relationship between DOC concentrations and other elements concentrations highlights the importance of TOC, TC, Fe(II) concentrations that affect the distribution variations of DOC in soil-water solutions (Table 1). The DOC concentrations are linearly correlated with TOC concentrations (Fig.5a). However, the magnitude of the ratio of DOC to TOC substantially varied through the profiles mainly because the removal of DOC with depth occurs as a result of chemical adsorption and biological degradation.

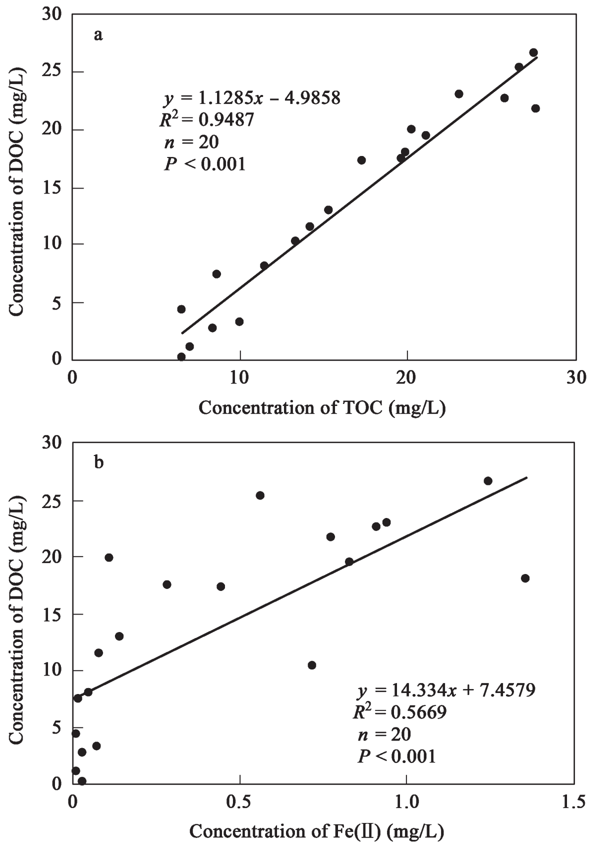

Fig. 5 Relationship between DOC and other elements in annular wetland soil-water solutions through soil profiles (0–40 cm). (a) relationship between DOC and TOC in annular wetland soil-water solutions through soil profiles; (b) relationship between DOC and Fe(II) in annular wetland soil-water solutions through soil profiles.

From "a" to "e", the ratio of DOC to TOC observed in soil-water solutions ranged from low values (average) of 67.5% to high values of 81.5% because the lateral input of the DOC was a major determinant of the amount of TOC presently. The DOC concentrations were linearly correlated with Fe(II) concentrations (Fig.5b). They are in the same orders of magnitude in annular wetland soil-water solutions as in contrast with the forest land. The factors lie in the high rich Fe of annular wetland soil and the coupling of the DOC and Fe(II) pathways.

The DOC concentrations showed negative correlations with TP concentrations (R = –0.397) and positive correlations with TN (R = 0.392) (Table 1). Although the relationships between DOC concentrations and TP, TN concentrations were rather weak, the influence of DOC on the transportation of other nutrients existed in annular wetland soil-water solutions. However, in the Soil Percolating Water of Chinese Fir Piantation, the DOC concentrations were highly correlated with TN (R^2 = 0.369) and free iron concentrations (R^2 = 0.598), suggesting the important influence of DOC on the transportation of other elements, especially nutrient elements, in the soil (Yu *et al*., 2006).

2.3 Controlling factors of DOC mobile in annular wetland soil

In all acid to very acid soils, C/N ratios of solid phase and pHs ($CaCl_2$, soil:solution = 1:2.5) are the controlling factors of DOC mobility on annual time scale. A multiple regression of DOC mobile has been conducted (Sommer, 2006). In the sample studied, the DOC concentrations show weak correlations with C/N ratios (R = 0.397, n = 15) and pHs (R = 0.399, n = 15) in the top soil (0–20 cm). This result is incompletely consistent with the study of Sommer (2006). The possible reasons could be that the soil solutions were analyzed for DOC concentrations from the samples of pot clay end soil solution extractor. The measured value of DOC concentrations, an average during the sampling, is lack of representation. The DOC concentrations declined from topsoil to subsoil in mineral soils due to DOC immobility increase with pH. However, at all sites, an increase in DOC concentrations in soil-water solutions was found at depth of 40–60 cm or 60–80 cm. It may be associated with formation of large pores in annular wetland soil during spring freezing and thawing. The DOC downward migrated with preferential flow caused by the soil pores and the amount of the DOC migration was proportional to the volume of water. Furthermore, the DOC concentrations from "a" to "e" were raised whose mobility was independent of pH and C/N of soils in annular wetland soil-water solutions. The potential of soil and sediment for providing DOC to natural waters depends on the content and the sorption coefficient of the DOC. Accordingly, it is

Table 1 Correlations between DOC and other elements in soil-water solutions

	TOC	pH	TP	TN	TC	IC	Fe(II)	Fe(III)
DOC	0.974	–0.235	–0.397	0.392	0.813	0.088	0.753	–0.111
Sig. (2-tailed)	0.00	0.318	0.083	0.087	0.00	0.712	0.00	0.641
Level of significance	0.01	–	–	–	0.01	–	0.01	–
n	20	20	20	20	20	20	20	20

not important whether soil water sampling represents the mobiliasation processes of DOC under natural conditions (Bishop *et al*., 1994) but the general hydrologic processes occurring within and around these wetlands (Casper *et al*., 2003). The continuous lateral flow in soils leads to substantial DOC export from edge to centre of the annular wetland.

3 Conclusions

The DOC concentrations of the annular wetland soil-water solutions decreased and then increased with increasing soil depth and the lowest value of the DOC concentrations appeared at depth of 20–40 cm or 40–60 cm. In the upper soil, DOC concentrations in soil-water solutions linearly increased from edge to center of the annular wetland.

The distribution variations are intimately linked to DOC production and utilization within the soils and DOC transport processes in annular wetland soil-water solutions. The concentrations of TOC, TC and Fe(II), DOC mobility and continuous vertical and lateral flow affect the distribution variations of DOC in soil-water solutions. These distribution characteristics suggest a systematic response of the distribution variations of DOC in annular wetland soil-water solutions to the geometry of closed depressions on a scale of small catchments. However, the DOC in soil pore waters of the annular wetland may be the potential source of DOC to stream flow on watershed scale and the DOC-rich water was originated from the upper soil horizons and formed a rapid running component into large rivers when they are connected by infrequent big flooding. These observations also implied the fragmentation of wetland landscape could bring the spatial-temporal variations of DOC distribution and exports in annular wetland soil-water solutions, which would bring negative environmental impact in watersheds of the Sanjiang Plain.

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