Soil C, N and P Stoichiometry of Shrub Communities in Chenier Wetlands in Yellow River Delta, China†

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The stoichiometry of C, N, P has improved understanding of nutrient circulation in ecosystems. However, little information is available about coastal wetlands. Here, wetland soil ecological stoichiometric features of carbon, nitrogen and phosphorus in two different shrub communities (*Tamarix chinensis* and *Ziziphus jujube*) in chenier of Yellow river delta were studied. The results showed that there was little soil total organic carbon content with large variation. The content of total nitrogen and phosphorus were extremely lacked, which might be two important nutrient limiting factors for these two plant communities. Soil R_{CN} was much higher than regional and global scales, however, R_{CP} and R_{NP} were far below those two scales. The variation of R_{CN}, R_{CP} and R_{NP} were 1.86, 67.62 and 106.32 %, which characterized relatively stable R_{CN} in 0-30 cm soil in this region. By multiple linear regression analysis, the vegetation community type and soil moisture were key factors affecting soil stoichiometric features.

Keywords: Soil stoichiometry, Yellow river delta, Chenier, Wetlands.

INTRODUCTION

The chemical composition of elements in the environment influences the relative elementary composition of organisms and *vice versa*, due to the absorption, utilization and release of elements by organisms, element content and body ratio also reflects the state and amount of elements in the environment[1]. Through the course of interactions between organisms and their environments, the regional element cycle tends to be stabilized and the ratios of chemical elements also tend to be balanced, both in the environment and within organisms. These dynamics enable stoichiometry to be utilized for studying the coupling relations among various environmental processes[2]. On earth, carbon, nitrogen and phosphorus form the basis of the chemical composition of all life forms; as such they are the major elements studied in stoichiometry and their ratios are inextricably linked to the function of ecosystem[3].

Many previous studies have indicated that, at a large scale, the C: N: P molar ratio (R_{CNP}) of living tissues is constant. For example, in marine, R_{CNP} is 106:16:1 for plankton, 307:30:1 for plants and 124:22:1 for arthropods. In terrestrial ecosystems the mean R_{CNP} is 968:28:1 for plants[1,4]. N and P are two important elements necessary for plant growth and the leaf N: P

ratio (R_{NP}) is commonly employed as a criterion to determine whether ecosystems or species are restricted by low N or P availability[3]. Such studies are highly instructive for identifying factors that restrict the growth, organism's evolution and more broadly, for revealing the impact of the biogeochemical cycle in various ecosystems. Thus, stoichiometry analyses of terrestrial and aquatic ecosystems have become an essential component of biological research. However, as of now, the burgeoning chemometric literature concentrates mainly on well-studied species and their communities, less attention has been paid to soil R_{CNP}[5,6].

Carbon, nitrogen and phosphorus content in the soil constitute not only a key and essential raw material for plants survival, but also an important determinant of both the primary productivity and biogeochemical cycle of the earth. The content of these three factors and their relative balance are closely related to the nutrient content and stoichiometric characteristics of plants and thus affect the plant growth, community species composition and productivity[7,8]. Coastal wetlands were transitional region between sea and land with harsh conditions. The size of soil carbon pools and proportion relationship with N and P elements, not only embody the wetland soil carbon consumptive and storage capacity, but also reflect the maintenance

mechanism of primary productivity in ecotone ecosystem[5,9-11]. However, up to now, stoichiometric studies of wetland soils are rare. Here, by using Chenier wetlands in Yellow river delta as study area, the research objectives were: (1) to study the soil R_{CNP} characteristics of chenier wetland ecosystem; (2) to examine the factors influencing soil stoichiometric characteristics. Further, a comparison of soil stoichiometric characteristics at global, country and local scale was conducted, to verify whether a similarly stable R_{CNP} ratio existence in chenier wetland soils.

EXPERIMENTAL

Study area: The study was conducted within the national nature reserve, in the chenier wetland ecosystem of the Yellow river delta, Wudi County, Shandong Province, China. The city lies in the East Asia Monsoon Continental Sub-humid Climate Zone, within the Warm Temperate Zone (N37º502 -38º202 , E117º502 -118º102). It is characterized by a mild climate, four distinct seasons with obvious wet and dry seasons, a mean temperature of 13.6 ºC and annual precipitation of 500-900 mm. The wide spatial distribution of mudflats and marshes is an important characteristic of this coastal wetland. Its soil matrix is constituted of shell, sand and mud, with a unit weight of 1.2 g/cm³, with a coarse particle diameter, large porosity, weak water and fertilizer retention and large daily temperature differences, with rapid rises in the daytime and rapid declines at night. The plants at the site are mainly perennial herbs with many modes of reproduction. *Tamarix chinensis* and *Ziziphus jujube* are two dominant shrubs that are relatively well-distributed. (1) *T. chinensis* is located near the high-water line on the seaward side of the ridge; due to the low ground-water level it is frequently accompanied by saline-alkaline tolerant plants such as *Zoysia macrostachya*, *Messerschmidia sibirica L.*, *Limonium bicolor* and *Scorzonera mongolica*, along with water-tolerant plants such as *Phragmites australis*. It tends to grow in colonies, with a low vegetation coverage (mean 42 %); bare soil is seen frequently in this environment and below the shrub there is very little or no layer of humus. (2) *Ziziphus jujube* is located on fixed/semi-fixed embankments on top of or behind the dune of the chenier. It coexists with *Artemisia mongolica* in most cases, with a high vegetation coverage (mean > 80 %) and a humus layer thickness of 0-1.0 cm (Table-1).

Sample collection: In mid-July 2013, 15 locations were chosen for soil sampling in *Tamarix Chinensis* and *Ziziphus jujube* communities (three to five years old and 1.22-1.95 m height, Table-1). In tree stem base, under canopy and crown outside, 0-30 cm soil cores with 5 cm increments were conducted. The sampled soil in same soil layer of each tree was mixed evenly, put into a plastic bag, sealed and brought to the lab for assessment. 180 soil samples were obtained.

Chemical analysis: In our laboratory the soils were screened immediately through 2 mm sieve. The part of the soil was measured, baked in a drying oven for at least 24 h at 105 ºC and its mass of water content was then determined. The remainder of each soil sample was air dried for 15 d. A part of that dried soil was used to determine the content of total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP). $K_2Cr_2O_7$-H_2SO_4 oxidation process is used to determine total organic carbon content, a flow injection analyzer (AA3) to determine total nitrogen content after heat digestion with H_2SO_4-$HClO_4$ and the Mo-Sb colorimetric method to determine total phosphorus contents after heat digestion with H_2SO_4-$HClO_4$.

Statistical analysis: The molar mass contents of C, N and P per unit mass (mol/kg) were obtained by dividing the measured mass content of each element (g/kg) by its atomic weight. The C:N, C:P and N:P ratios (R_{CN}, R_{CP} and R_{NP}) were calculated from the molar mass contents of each soil sample[12]. The mean content of total organic carbon, total nitrogen and total phosphorus of all samples was used as the pattern of shrub communities' soil nutrient. In order to compare the variance between *Tamarix chinensis* and *Ziziphus jujube* community, the mean nutrient content and molar ratios of elements from the 0-30 cm soil layer in each of the two communities were determined and these measures were used in a difference test ($p < 0.05$). A multivariate regression analysis was conducted between community's type, soil depth, soil water content, groundwater level and the total organic carbon, total nitrogen, total phosphorus content, C:N, C:P and N:P ratios at an alpha level of 0.05. Analyses were conducted using the Excel 2003 and SPSS11.0 software.

RESULTS AND DISCUSSION

Soil C, N and P stoichiometry of shrub communities in chenier wetlands: Soil C, N and P in 0-30cm soil depth averaged 3.73, 0.11 and 0.14 g/kg in chenier shrub communities and the coefficient of variation was 100.80, 90.91 and 50 %, respectively (Table-2). R_{CNP} was 66.73:1.69:1, while R_{CN}, R_{CP} and R_{NP} were 53.73, 62.39 and 2.60 with 1.86, 67.62 and 106.32 % variance, respectively.

Factors analysis of soil C, N, P stoichiometry: A multivariate regression analysis showed that vegetation type and soil water content were two important factors that influenced the content total organic carbon, total nitrogen and total phosphorus of chenier soils, in addition to the community type to R_{CN} and soil moisture to R_{NP} (Table-3). However, soil depth and groundwater level had no influence on the C, N and P stoichiometry.

The coastal wetland ecosystem is the area that experiences the most intensive biogeochemical cycling at the marine-terrestrial interface. Being a vulnerable ecological belt, it has always been a hot spot for wetland researchers[5,10,11]. The chenier wetland of Yellow river delta is a beach ridge or dune-shaped coastal wetland, most of which are a large amount number of

TABLE-1
SUMMARY OF COMMUNITY IN CHENIER OF YELLOW RIVER DELTA

Community	Groundwater level (m)	Tree age (a)	Tree height (m)	Associated species
T. chinensis	0.5-0.7	3-5	1.22-1.63	*Zoysia macrostachya, Messerschmidia sibirica, Limonium bicolor, Scorzonera mongolica, Phragmites australis*
Z. jujube	0.75-1.5	4-5	1.25-1.95	*Artemisia mongolica, Metaplexis japonica, Aster tataricus*

			TABLE-2				
		SOIL C, N AND P CONTENT AND RATIOS IN CHENIER IN YELLOW RIVER DELTA					
Community	TOC	TN	TP	R_{CN}	R_{CP}	R_{NP}	R_{CNP}
T. chinensis	1.49 ± 0.79*	0.04 ± 0.02*	0.11 ± 0.04*	58.15 ± 36.19^{ns}	38.21 ± 20.09*	0.88 ± 0.55*	38.21:0.88:1
Z. jujube	6.03 ± 4.19	0.18 ± 0.10	0.18 ± 0.08	49.30 ± 36.63	86.58 ± 44.69	2.60 ± 2.25	86.58:2.6:1
Average	3.73 ± 3.76	0.11 ± 0.10	0.14 ± 0.07	53.73 ± 36.58	62.39 ± 42.19	1.74 ± 1.85	62.39:1.74:1
TOC = Total organic carbon; TN = Total nitrogen; TP = Total phosphorus.							

	TABLE-3			
	EFFECTING FACTORS ANALYSIS OF SOIL R_{CN}, R_{CP}			
	AND R_{NP} IN CHENIER IN YELLOW RIVER DELTA			
	Significance P			
Indicators	Groundwater level	Community	Water content	Soil depth
TOC	0.108	0.000	0.000	0.008
TN	0.127	0.000	0.000	0.181
TP	0.426	0.001	0.000	0.000
R_{CN}	0.355	0.26	0.003	0.540
R_{CP}	0.289	0.001	0.000	0.672
R_{NP}	0.268	0.001	0.693	0.216

shell fragments deposited on shore by sea winds and waves. This chenier has important academic value for the study about the area's coastline dynamics and paleo environmental and global climate change understanding, as well as maintaining backshore ecological environment stability[13]. It is puzzling, then, that little research has been published about this area to date. Since 2008, a large-area general vegetation investigation in this area has been conducted and found that *T. chinensis* and *Z. jujube* represent two dominant shrub communities most widely distributed here. These two species play a vital role in promoting siltation, improving the ecological environment and maintaining species' diversity. In order to thoroughly understand the soil-plant interactions and elementary cycles in chenier ecosystem, the soil total organic carbon, total nitrogen and total phosphorus contents in the two shrub communities were studied, striving to interpret the patterns of soil elementary composition and stoichiometry. There was little soil nutrient in shrub communities, with average content about 3.73, 0.11 and 0.14 g/kg of total organic carbon, total nitrogen and total phosphorus, which were similar to the Tibetan Plateau alpine wetlands, but far below the Sanjiang Plain Wetlands (Table-4). Also, there are significant variance in total organic carbon, total nitrogen and total phosphorus content about 100.80, 90.91 and 50.00 %, respectively. The cause of this may be the location of these two plant communities. *T. chinensis* community was near the high tide line with frequent sea wave erosion, bare ground and surface soil organic matter lack, while *Z. jujube* was located leeward of the chenier, more litter could accumu-

late than that in *T. chinensis* community. P is often considered the main limiting factor in wetland ecosystems with rapid P leaching by wave erosion[14]. Total phosphorus content in chenier soil was far lower than that in typical seasonal flooding wetland of the Yellow river delta[15]. This lower P content may be caused by weak soil phosphorus adsorption owing to coarser soil and less clay composition in soil[16]. So that, phosphorus deficiency may be an important factor restricted plants growth in the area.

Since the "Redfield ratio" was proposed in 1958, many studies have confirmed the stable Redfield ratio characteristics of terrestrial and marine organisms[17,18]. Some authors have suggested that, as raw source and released pool of elements to plants, the soil system may also manifest a consistent R_{CNP} ratio over time[8,12]. Compared to the global and regional scales, larger R_{CN} was found in chenier shrub soils in Yellow river delta ($R_{CN} = 53.73$), which might relate to the soil matrix with most shell residues, large N consumed by microbial decomposition and quickly absorption by plants after release (Table-4). However, large R_{CN} might manifest initial stages of soil nitrogen mineralization. The microbial assimilation would exceed mineralization, which may make the plant nitrogen deficiency phenomenon particularly serious[19]. Thus, it could be speculated that the plant in this area may be limited by soil N element. In addition, R_{CP} and R_{NP} of shrub soil in chenier wetland in Yellow river delta was far below the level of regional and the global scale (62.39 and 1.74, respectively). The cause may be less organic carbon distribution and low continuous flooding frequency leading to less soil P leaching and relatively high holding[20] and what more, study scale may also be an important cause[21].

Coastal wetland is an ecological transition zone with many environmental factors intense acting and, the soil is a natural complex caused by parent material, topography, biology, climate, time and other factors, so the soil chemical patterns influenced by various factors[5]. In this paper, according to multivariate linear regression, plant community type and soil moisture affected total organic carbon, total nitrogen, total phosphorus content and stoichiometric ratio significantly, however, the impact of soil depth and water table on soil CNP stoichiometry

	TABLE-4							
	TOP SOIL TOC, TN, TP CONTENT AND RATIOS IN DIFFERENT WETLANDS IN CHINA AND WORLD SCALE							
Site	Soil depth and type	TOC	TN	TP	R_{CN}	R_{CP}	R_{NP}	Cited reference
Alpine wetland	0-30 cm	3.6	0.2	1.0	17.5	9.3	0.53	22
Sanjiang plain	0-20 cm	203.5	20.2	1.4	11.8	530	45	23
	D. angustifolia	–	–	–	13.0	90.5	6.1	5
	C. lasiocarpa	–	–	–	13.9	467.5	25.7	
Typical seasonal flooding wetland of the Yellow river delta	0-10 cm	–	–	0.66	–	–	–	15
China soil	0-10 cm	–	–	–	14.4	136	9.3	12
World scale	0-10 cm	–	–	–	14.3	186	13	8
TOC = Total organic carbon; TN = Total nitrogen; TP = Total phosphorus.								

were not. The community types showed changes of distance from the sea, waves (or wind) erosion, soil particle composition, altitude, species' composition and properties, organic matter presence or absence, water holding and element releasing patterns. The content of soil total organic carbon, total nitrogen and total phosphorus in *Z. jujube* community were higher than that in *T. chinensis* community, so that there was significant difference among R_{CP} and R_{NP} (Table-2). Nevertheless, no significant difference was found in R_{CN} in two communities that implied that there maybe stable soil ratio of R_{CN} in this area. Further research is needed to determine whether this indicated the relationships and processes during carbon and nitrogen cycling in shell detritus soil matrix in Coast wetlands.

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