Ecological Stoichiometric Characteristics of Carbon, Nitrogen and Phosphorus in an Urban Wetland in Qinghai-Tibetan Plateau

——Taking Huoshaogou wetland in Xining City as an example

Xiao-jun LIU
Key Laboratory of Qinghai-Tibetan Plateau Resources and Environment, College of Life and Geographic Science
Qinghai Normal University
Xining, China,
e-mail:775046702@qq.com

Xu-feng MAO*
Key Laboratory of Qinghai-Tibetan Plateau Resources and Environment,
Qinghai Normal University
Xining, China
e-mail: maoxufeng@yeah.net

Xiao-yan WEI
Institute of Panchen Lama
Qinghai Normal University
Xining, China
e-mail: weixiaoyan4477@163.com

Abstract—Ecological stoichiometry has been widely applied to ecosystem management around the world, mainly through analysis of carbon(C), nitrogen and phosphorus (P). Ecological stoichiometric characteristics have important imply meaning on key processes and mechanisms of protection, restoration and reconstruction of urban wetlands. This study selected the Huoshaogou urban wetland of Xining city as a case study. On the basis of experimental analysis data, we analyzed the characteristics of C, N and P contents and the inner coupling relationships among the C, N and P in sediments and plants of this wetland. Results indicated that: 1) The contents of the C in sediments are high and the C, N and P contents in the plants are relative low. N and P in the sediments are, respectively, mainly at "level 1" and "level 4" in national soil nutrient classifications.2) Limiting factors of plants growth: P may limit the plants growth in 1-5 cascades, N may limit the plants growth in 6-9 cascades; 3) There are statistically significant correlations between C and C/P in the sediments and N/P in the plants($P<0.05$). The current results may provide theoretical support for the management of the Huoshaogou wetland.

Keywords-Ecological stoichiometric characteristics; sediments; plants; Urban wetlands

I. INTRODUCTION

As an important part of urban social-ecological systems [1, 2], urban wetlands provide significant ecological, environmental and social services [3]. With the acceleration of urbanization processes, unreasonable development and utilization have resulted in various problems in urban wetlands, such as area reducing, water pollution, biodiversity decreasing and functional degradation, etc. [4]

Ecological stoichiometry refers to research multiple chemical elements(C, N and P) in different ecosystems [5]. It is an effective method to learn the characteristics of C, N and P contents and coupling relationships among the different elements in plants and sediments [6]. Then we can understand the states of plants and the balance of whole ecosystems [7]. Thus, Ecological stoichiometry characteristics have direct indication significance on key processes and mechanisms of protection, restoration and reconstruction of urban wetlands [8-11]. There are a large number of studies on ecological stoichiometry in different spatio-temporal scales, for different ecosystem types [7] and vegetation types [12-13]. It is necessary to do more research on urban wetlands on the Qinghai-Tibetan Plateau for the two reasons: 1) The processes and technologies of protection, restoration and reconstruction on urban wetlands are obviously different from the natural wetlands and difficult to develop; 2) In the alpine region, ecological environment of urban wetlands is fragile and more sensitive to climate change, human impact and urbanization and need more attentions. Therefore, it is significant to take an urban wetland on the Qinghai-Tibetan Plateau as a research object.

C, N and P are the necessary nutritional elements in plants growth and function exertion [13], cycles of them affect ecosystem productivity [14]. Ratios of C, N and P have important implications for plants [15]: C/N and C/P indicate the biological nutrient usage efficiency [16] and states of biological community structure, function and productivity [17]; N/P reflects if the N or P limits plants growth [18]. Thus, Ecological stoichiometry characteristics of C, N and P could indirectly tell us the interactive relationships between the plants and sediments and nutrient utilization strategies of plants [19]. It is also useful to understand inner balance mechanisms of ecosystems, and provides strong theoretical support for urban wetland management [20, 21].

Copyright © 2017, the Authors. Published by Atlantis Press.
This is an open access article under the CC BY-NC license (http://creativecommons.org/licenses/by-nc/4.0/).

II. STUDY AREA

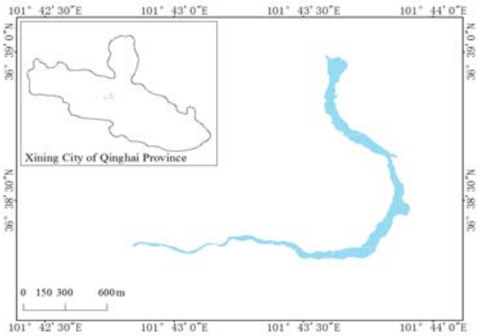

Figure 1. The location and cascades of Huoshaogou river wetland.

The Huoshaogou River Wetland is located in eastern Xining city, Qinghai Province(N36°38'15"-36°39'01", E101°42'40"-101°43'55")(Fig.1). The Huoshaogou River is a first tributary of the Huangshui River and the second tributary of the Yellow River. The area of the Huoshaogou river basin is 131 km^2 and its climate is continental plateau semi-arid, with thin air, long hours of sunshine and strong ultraviolet radiation.

For frequent human activities and sparse plants, soil erosion of the Huoshaogou wetland used to be very serious. In 2006, the river downstream restoration project had been carried out and 9 cascade wetlands were constructed. With the proceeding of restoration project, the ecological structure and function of the Huoshaogou wetland have been restored, making the wetland an important landscape in the Xining city.

III. MATERIAL METHOD

A. Samples Collection and Pretreatment

Sediment and plant samples were collected in September 2015. Plants samples and sediments were collected in each cascade. All the samples were baked at 105°*C* for 30 minutes, then put in a drying box (80°*C*) until the samples were dried completely. Finally, samples were weighed and sieved over mesh-sizes of 100 mm.

B. Indoor Determination

The contents of total organic carbon (TOC) in the sediments and plants were respectively determined by potassium permanganate oxidation external heating method and the Italian ouvert element analyzer (EA3000). The contents of total nitrogen (TN) and total phosphorus (TP) were determined, respectively, by the Alkaline potassium per sulfate digestion ultraviolet spectrophotometer and ammonium molybdate spectrophotometer method.

C. Data Processing

The average, maximum, minimum, range and coefficient of variation of C, N, P and C/N, C/P, N/P of the sediments and plants were processed by Excel 2003; The correlations of C, N, P, C/N, C/P and N/P between the sediments and the plants were processed by SPSS19.

IV. RESULTS

A. The General Characteristics of C, N, P of Sediments

TABLE I. THE CHARACTERISTICS OF C, N AND P CONTENTS IN SEDIMENTS OF EVERY CASCADE OF THE WETLAND((MG/G))

Elements	Average value	Minimum	Maximum	Coefficient of variation
C	23.66	18.29	30.19	0.16
N	2.34	1.72	3.23	0.21
P	0.66	0.45	1.09	0.33

The contents of C, N and P in sediments of the Huoshaogou wetland are shown in Table Ⅰ, and the average contents of C, N and P are, respectively, 23.66mg/g, 2.34mg/g and 0.66mg/g. The spatial variations of C, N and P in sediments are significant(Fig Ⅱ): Basically, the contents of C and N changed with the decreasing cascades. C and N are closely linked and mutual influenced($r=0.74$, $P<0.05$). A similar relationship between the contents of C and N was observed as follows: The highest value of C and N appeared in the 3rd cascades, the lowest value appeared in the 5th cascades. C and N contents have a sudden decline in the 6th and 7th cascade, respectively. The contents of P decreases markedly with the descending cascades, and the highest values and the lowest values are, respectively, in the 8th and 2st cascade.

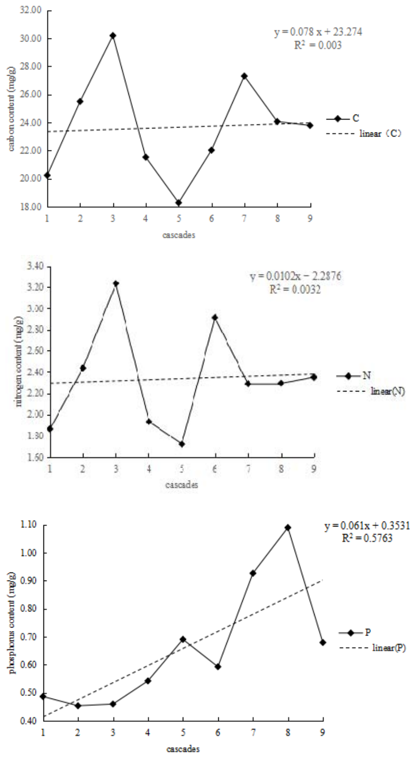

Figure 2. The variation tendency of C, N and P in sediments of cascades.

B. Characteristics of C, N, P Contents in Dominant Plants

TABLE II. THE CHARACTERISTICS OF C, N AND P CONTENTS IN DOMINANT PLANTS OF EVERY CASCADE OF THE WETLAND(MG/G)

Life forms	**Elements**	**Average value**	**Minimum**	**Maximum**	**Coefficient of variation**
All plants	C	296.37	84.55	447.8	0.34
	N	12.47	5.66	26.14	0.50
	P	0.85	0.21	1.83	0.58
Emergent plants	C	354.19	220.79	447.80	0.15
	N	11.09	5.66	26.14	0.57
	P	0.75	0.21	1.83	0.71
Submerged plants	C	209.64	84.55	344.35	0.45
	N	14.55	7.68	22.55	0.41
	P	0.99	0.32	1.75	0.43

As is shown in Table Ⅱ, the mean values of C, N and P contents are, respectively, 296.37mg/g, 12.47mg/g and 0.85mg/g. The contents of N and P in submerged plants are slightly higher than emergent plants. The spatial variation of C contents in the emergent plants is more stable than the submerged plants. There is no significant difference in degree of spatial variation among the C, N and P. Four dominant plants, including *Typha minima*, *Reed*, *Potamogeton perfoliatus*, and *Keratinocytes* were examined in the current study. *Typha minima* has the highest contents of C(447.8mg/g). *Potamogeton perfoliatus* has the highest contents of N and P.

C. Ecological Stiochiometry Charariteristics of C, N, P of Sediments and Plants

TABLE III. THE CHARACTERISTICS OF C/N、C/P AND N/P OF SEDIMENTS AND PLANTS

	Element ratios	**Average value**	**Minimum**	**Maximum**	**Coefficient of variation**
Sediments	C/N	10.28	7.56	11.92	0.12
	C/P	39.25	22.09	65.63	0.36
	N/P	3.92	2.11	7.03	0.41
All plants	C/N	30.61	9.02	64.20	0.63
	C/P	560.68	82.28	1799.57	0.85
	N/P	16.74	9.12	29.04	0.36
Emergent plants	C/N	40.50	11.41	64.20	0.62
	C/P	749.54	120.68	1799.57	0.97
	N/P	17.23	10.44	29.04	0.40
Submerged plants	C/N	15.79	9.02	38.54	0.44
	C/P	277.39	82.28	913.64	0.67
	N/P	16.00	9.12	26.97	0.35

As depicted in Table Ⅲ, C/N, C/P and N/P are fluctuated in different cascades. This is consistent with the theory of dynamic equilibrium[21]. Variation coefficient of plants is ranked as C/N>C/P>N/P. C/N and C/P in emergent plants and the submerged plants presented big difference, since different wetland plants have ability in carbon absorption. Average value of C/N(40.50) in emergent plants is higher than that of the submerged plants(15.79), indicating higher N utilization efficiency in emergent plants.

V. DISCUSSION

A. Effects of Plants on Sediments

TABLE IV. THE NATIONAL SOIL NUTRIENT CLASSIFICATIONS STANDARD[22]

Elements	**Levels**					
	1	***2***	***3***	***4***	***5***	***6***
N(mg/g)	>2	1.5-2.0	1.0-1.5	1.75-1.0	0.5-0.75	<0.5
P(mg/g)	>1	0.8-1.0	0.6-0.8	0.4-0.6	1.2-0.4	<0.2

The average C content in Huoshaogou sediments is much higher than that of Yangtze River [23](0.82mg/g) and Yellow River[23](0.23mg/g). Lower water velocity and higher vegetation may contribute to the above results [24,25]. According to standards in Table Ⅳ, most of sediments (N) are at "level 1" of national soil nutrient classifications. N in sediments is mainly derived from plants residues and biological nitrogen fixation [26]· and a small amount of N comes from precipitation and flood transportation [27]· The contents of N are significantly lower than marsh wetlands of Jilin Province [28], and the contents of C, N and P in the river wetlands are significantly lower than the lakes and swamps [29]. Organic matter decomposes slowly under the anoxic condition, which lead peat accumulation is more significant and the greater amount of N accumulation. That also can explain why the contents of N in sediments are significantly higher than a river wetland in Ningxia Province [29]. The values of C/N in sediments are within the average range values in Chinese soil (10-12) [30]. The average value of C/P in sediments is lower than C/P average values in Chinese soil [31]. C/P indicate the ability of sediments bacteria to release and fixation of P[29] and low C/P indicates low availability of P[19]. N/P in sediments are higher than the other study results [19, 32-33], indicating lower contents of P in the Huoshaogou wetland.

The highest C and N in sediments appeared at the 3rd cascade. *Reed* and *Typha minima* have obvious effect on the recycles of C and N. The lowest contents of C and N appeared in the 5th cascade. The spatial variability of P contents is significant and they declined with the decreasing cascades. This is different from the results of grassland ecosystem in the hilly area of Loess plateau [34]. The highest contents of P(1.09mg/g) appeared in the 8th cascade and the lowest P contents (0.45mg/g) appeared in the 2nd cascade.

B. Nutrient Utilization Strategies of Plants

The average content of C in dominant plants of Huoshaogou wetland is lower than the forest ecosystem in the north and south transects in eastern China (480.1mg/g)[35]. N and P are lower than the average contents (13.54mg/g, 1.72mg/g) of China wetlands [18]. N and P in plants are significant mutual correlated ($r=0.84, P<0.05$). N is significant correlated with P in Emergent plants ($r=0.91, P<0.05$). There is no significant correlation among the C, N, and P in submerged plants, indicate that weak synergies in C, N and P [21]. The maximum C/P in plants is 1799.57, indicating the maximum use-effectiveness of P. The values of N/P are higher than the average values of terrestrial plants in China [35,36](14.4).

If N/P is less than 14, there is N limitation. Contrarily, there is P limitation [37]. These limitations would affect the nutrition absorb efficiency and photosynthetic capacity of plants [38]. Plants of 1-5 cascades are mainly limited by the P and plants in 6-9 cascades are mainly limited by the N. It is not reasonable to conclude that these nutrient supply deficiencies based on the low contents of certain elements in blades [39]. The indicating functions of N/P in different blades should be determined by specific region, ecosystem, and species [40].

TABLE V. CORRELATIONS AMONG C, N, P CONTENTS AND C/N、C/P、N/P IN SEDIMENTS AND PLANTS

		sediments					
		C	***N***	***P***	***C/N***	***C/P***	***N/P***
Plants	C	0.55	0.09	0.40	0.46	0.04	-0.11
	N	-0.12	-0.38	0.06	0.46	-0.12	-0.25
	P	-0.41	-0.53	0.09	0.37	-0.31	-0.38
	C/N	0.45	0.30	0.18	0.2	0.28	0.24
	C/P	0.60	0.05	-0.2	-0.1	0.53	0.5
	N/P	0.7*	0.57	-0.4	-0.12	0.73*	0.66

*. Indicate P<0.05.

As is shown in Table Ⅴ, there are no significant correlations between C, N, P, C/N, C/P, N/P in sediments and C, N, P in plants, which are different from the study results of Poyang Lake [30] and Minjiang Estuary [7]. These results may be related to different regions, sampling methods, etc. There is a significant correlation among C, C/N and N/P in plants (P <0.05), as the C and N in plants may indirectly affect the absorbing ability for N and P and then change the N/P.

VI. CONCLUSIONS

We analyzed the ecological stoichiometric characteristics of C, N and P in the sediments and plants in the Huoshaogou wetland, and discussed the effects of the plants on the C, N and P in the sediments and plants nutrient utilization strategies. The main conclusions are as follows:

1) The large input of plants litters and the strengthening of humification improve the contents of C and N in the sediments of the Huoshaogou wetland. The contents of C are high, N and P in the sediments are, respectively, mainly at "level 1" and "level 4" of national soil nutrient classifications. The spatial variability of C, N and P in sediments is significant, maybe affected by the distribution of plants or the cascades.

2) The absorbing capacities of plants for C, N and P in Huoshaogou wetland are not strong enough, and the productivity of plants in this wetland is low. The plants of 1-5 cascades and the 6-9 cascades are, respectively, mainly limited by P and N.

3) C, N, P, C/N, C/P and N/P in sediments are not significant correlated with C, N and P in plants, and contents of C and C/N of sediments are correlated with N/P of plants (P<0.05). The relationships between sediments and plants are not clear enough and still need further study.

ACKNOWLEDGMENT

This work is supported by National Natural Science Foundation of China (51669028&51409144) and National Key Scientific Research Project (2016YFC0501906-1).

REFERENCES

[1] J. H. Wang, and X. G. Lv, “Urban wetland: its concept, ecological services and protection,” Chinese Journal of Ecology, vol. 26, Dec. 2007, p. 555-560, doi: 10.13292/j.1000-4890.2007.0101.

[2] C. H. Li, L. J. Jiang, and G. Guang, “Achievements, limitation and prospectives: overseas urban wetlands researches,” Journal of Central South University of Forestry &Twchnology, vol. 32, Dec. 2012, p. 25-30, doi: 10.14067/j.Cnki.1673-923x.2012.12.014.

[3] G. Y. Sun, H. X. Wang, and S. P. Yu, “The research advances and prospect of ecological stoichiometry,” Acta Ecologica Sinica, vol. 23, Sep. 2004, p. 94-100.

[4] C. H. Li, X. K. Zheng, G. Guang, Y. P. Cai, N. Shen, and A. P. Pang, “Research progress in protection and restoration of urban wetlands,” Progress in Geogrephy, vol. 28, Mar. 2009, p. 271-279.

[5] J. J. Elser, R. W. Sterner, E. Gorokhova, W. F. Fagan, T. A. Markow, and J. B. Cotner, “Biological stoichiometry from genes to ecosystems,” Ecology Letters, vol. 3, Nov. 2000, p.540-550, doi:10.1111/j.1461-0248.2000.00185.x.

[6] L. X. Zhang, Y. F. Bai, and X. G. Han, “Application of N:P stoichiometry to ecology studies,” Acta Botanica Sinica, vol. 45, Apr. 2003, p. 1009-1018.

[7] B. Chen, Y. J. Zhao, W. G. Zhang, and S. Q. An, “The research advances and prospect of ecological stoichiometry,” Acta Ecologica Sinica, vol. 30, Dec. 2010, p. 1628-1637.

[8] X. W. Zhou, H. L. Gong, W. J. Zhao, X. J. Li, Z. N. Gong, and Z. F. Zhang, “Dynamic monitoring and analysis of wetland resources in Beijing,” Acta Geographica Sinica, vol. 61, Jun. 2006, p. 654-662.

[9] W. X. Ou, L. F. Ye, X. X. Sun, and J. Y. Gong, “The effect of spatial scales on wetland functions evaluation: a case study forcoastal wetlands in Yancheng, Jiangshu Province,” Jiangshu Province.Acta Ecologica Sinica, vol. 31, Jul. 2011, p. 3270-3276.

[10] X. L. Wang, H. Z. Xu, and S. M. Cai, “Wetland protection and basin management in the middle and lower reaches of the Yangtze River,” Resources and Environment in the Yangtze Basin, vol. 15, Sep. 2006, p. 564-568.

[11] Y. S. Peng, Y. W. Zhou, and G. Z. Chen, “The restoration of mangrove wetland: a review,” Acta Ecologica Sinica, vol. 28, Feb. 2008, p. 786-797.

[12] D. H. Zeng, and G. S. Cheng, “Ecoligical stoichiometry: a science to explore the complexity of living systems,” Acta Phytoecologica Sinica, vol. 29, May. 2005, p. 1007-1019.

[13] Y. Y. Ma, and W. Q. Wang, “Carbon, nitrogen and phosphorus content and the ecological stoichiometric ratios of paddy field soil-plants in Minjiang River Estuary,” Subtropical Agriculture Research, vol.7, Agu. 2011, p. 182-187, doi: 10.13321/ j.Cnki.Subtrop.Agric. Res.2011.03.007.

[14] M. X. Liu, and K. J. Zhu, “Characteristics of nitrogen and phosphorus stoichiometry of plants in different funtional groups on Alpine meadow in the eastern edge of Tibetan Plateau,” Cinese Journal of Grassland, vol. 35, Mar. 2013, p. 52-58.

[15] D. P. Zeng, L. L. Jiang, and C. S. Zeng, “Reviews on the ecological stoichiometry characteristics and its applications,” Acta Ecologica Sinica, vol. 33, Sep. 2013, p. 5484-5492.

[16] T. G. Wu, W. Ming, and L. Liu, “Seasonal variations of leaf nitrogen and phosphorus stoichiometry of three Herbaceous species in Hangzhou Bay coastal wetlands, China,” Chinese Journal of Plant Ecology, vol. 34, Jan. 2010, p. 23-28.

[17] J. Lu, H. X. Zhou, G. Y. Tian, and G. H. Liu, “Nitrogen and phosphorus contents in 44 wetland species from the Lake Erhai basin,” Acta Ecologica Sinica, vol. 31, Aug. 2011, p. 1041-1052.

[18] W. F. Hu, W. L. Zhang, L. H. Zhang, X. Y. Chen, W. Lin, and C. S. Zeng, “Stoichiometric characteristics of nitrogen and phosphorus in major wetland vegetation of China,” Chinese Journal of Plant Ecology , vol. 38, Jul. 2014, p. 1041-1052.

[19] S. Q. Wang, and G. R. Yu, “Ecological stoichiometry characteristics of ecosystem carbon, nitrogen and phosphorus elements,” Acta Ecologica Sinica, vol. 28, Aug. 2008, p. 3837-3846.

[20] Z. X. Wang, “Research advantage and prospect of ecological stoichiometry in China,” Journal of Green Science and Technology, vol. 7, Jul. 2011, p. 195-196.

[21] X. H. Liu, “C, N, P stoichiometry of plants and soil in the wetland of Yellow River delta,” Shandong Agricultural University, Feb. 2013, p. 36-38.

[22] National Soil Survey Office, “Soil census and technology of China,” Beijing: China Agriculture Press, 1992, p. 111-112.

[23] S. Y. Yang, H. S. Jung, and C. X. Li, “Major element geochemistry of sediments from Chinese and Korean Rivers,” Geochimical, vol. 33, May. 2004, p. 99-105.

[24] K. Yang, X. Deng, X. L. Li, and P. Wen, “Impacts of hydroelectric cascade exploitation on river ecosystem and landscape: a review,” Chinese Journal of Applied Ecology, vol. 22, Dec. 2011, p. 1359-1367, doi: 10.13287/j. 1001-9332.2011.0181.

[25] Z. M. Zhang, S. X. Lin, Q. H. Zhang, Y. Guo, and C. H. Lin, “The distribution characteristics of soil carbon, nitrogen and phosphosporus under different land use patterns in Caohai Plateau wetland,” Jounal of Soil and Water Conservation, vol. 27, Dec. 2013, p. 199-204, doi: 10.13870/j.cnki.stbcxb.2013.06.024.

[26] J. Shuang, “Wetland biogeochemistry research,” Wetland Science, vol. 3, Dec. 2005, p.302-308, doi: 10.13248/j.Cnki.Wetlandsci.2005.04.010.

[27] G. Ge, Y. H. Xu, L. Zhao, Z. Q. Wu, and L. Wu, “Spatial distribution characteristics of soil organic matter and nitrogen in the Poyang Lake wetland,” Resources and Environment in the Yangtze Basin, vol. 19, Jul. 2010, p. 619-622.

[28] Y. Xiao, L. N. Shang, Z. G. Huang, W. G. Zhang, Z. S. Xue, and Z. S. Zhang, “Ecological stoichiometry characteristics of soil carbon, nitrogen and phosphorus in mountain swamps of eastern Jilin Province,” Scientia Geographica Sinica, vol. 34, Aug. 2014, p. 999-1001.

[29] X. Y. Bu, W. B. Mi, H. Xu, X. Y. Zhang, N. Mi, and Y. Y. Song, “Contents and ecological stoichiometry characteristics of soil carbon, nitrogen and phosphorus in wetlands of Ningxia Plain,” Scientia Geographica Sinica, vol. 42, Apr. 2016, p. 107-118.

[30] C. Y. Huang, “Soil science,” Beijing: China Agriculture Press, 2000, p. 297-305.

[31] H. Y. Gan, S. Z. Zhang, K. Liang, J. Q. Lin, and Z. C. Zheng, “Nutrients distribution and contamination assessment in seawater and surface sediments of the coastal wetlands, northern Beibu Gulf,” Wetland Science, vol. 10, Sep 2012, p. 285-298, doi: 10.13248/j. Cnki.Wetlandsci.2012.03.009.

[32] L. Q. Nie, Q. Wu, Bo. Rao, S. Fu, and Q. W. Hu, “Leaf litter and soil carbon , nitrogen, and phosphorus stoichiometry of dominant plant species in the Poyang Lake wetland,” Acta Ecologica Sinica,, vol. 36,Apr. 2016, p. 1-9.

[33] S. Fu, Q. W, Y. Bo, L. Q. Nie, J. Y. Huang, and Q. W. Hu, “Distribution of soil carbon-nitrogen, carbon-phosphorus and nitrogen-phosphorus ratios along Water level gradient in Nanji,” Wetland Science, vol. 13, Mar. 2015, p. 374-380, doi: 10.13248/j. Cnki.Wetlandsci.2015.03.017.

[34] H. Liu, and J. L. Lv, “Study on soil microbial biomass and soil ecological stoichiometry characteristics under different vegetation types in the Loess Plateau,” Acta Agriculturae Boreali-occidentalis Sinica, vol. 25, May. 2016, p. 779-787.

[35] S. J. Ren, G. R. Yu, C. M. Jiang, H. J. Fang, and X. M. Sun, “Stoichiometric characteristics of leaf carbon, nitrogen, and phosphorus of 102 dominant species in forest ecosystems along the north-south transect of east China,” Chinese Journal of Applied Ecology, vol. 23, Feb. 2012, p.581-586.

[36] W. X. Han, J. Y. Fan, D. L. Guo, and Y. Zhang, “Leaf nitrogen and phosphorus stoichiometry across 753 terrestrial plant species in China,” New Phytologist, vol. 168, Jun. 2005, p.337-385.

[37] W. Koerselman, AFM. Meuleman, “The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation,” Journal of Applied Ecology, vol. 33, Dec. 1996, p.1441-1450.

[38] S. Cordell, G. Goldstein, F. C. Meinzer, and P. M. Vitousek, “Morphological and physiological adjustment to N and P fertilization in nutrient limited Metrosideros polymorpha canopy trees in Hawaii.” Tree Physiology, vol. 21, Oct. 2001, p.43-50.

[39] E. R. Yan, X. H. Wang, M. Guo, Z. Qiang, and W. Zhou, “C:N:P stoichiometry across evergreen broad leaved forests, evergreen coniferous forests and deciduous broadleaved forests in the Tiantong region, Zhejiang Province, eastern China,” New Phytologist, vol. 34, Feb. 2010, p.48-57.

[40] L. X. Zhang, Y. F. Bai, and X. G. Han, “Differential responses of N: P stoichiometry of Leymus chinensis and Carex korshinskyi to N addition in a steppe ecosystem in Nei Mongol,” Acta Botanica Sinica, Vol. 46, Oct. 2004, p.259-270.