Front. For. China 2007, 2(4): 366–375
DOI 10.1007/s11461-007-0059-3

RESEARCH ARTICLE

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Biomass structure and nitrogen, phosphorus nutrient of *Calamagrostis angustifolia* populations in different communities of Sanjiang Plain, Northeast China

Abstract *Calamagrostis angustifolia* is the dominant species in the typical meadow and marsh meadow communities of Sanjiang Plain. The study on its biomass, the nitrogen (N) and phosphorus (P) contents in its different organs showed that the biomass of different *C. angustifolia* organs in the two types of wetland communities was distinctly different, which could be described by polynomial. The biomass of aboveground part and each organ presented single peak changing, with the maximum value of the latter occurred 15 days after. The *F*/*C* values were all less than 1, which were bigger in typical meadow than those in marsh meadow. The total N and P contents in different organs of aboveground part all descended monotonically in growth season, with the order of leaf > vagina > stem. The change of total N content in roots of the two types of *C. angustifolia* was consistent, while that of total P was quite different. The content of total N, ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N), especially of NH_4^+-N and NO_3^--N, varied widely in different organs, with NH_4^+-N/NO_3^--N > 1. Root was the important storage of N and P, but the storage of N and P in stem, leaf and vagina fluctuated greatly. The N/P ratios of the two types of *C. angustifolia* were all less than 14, which implied that N might be the limiting nutrient of *C. angustifolia*, and the limitation degree was higher in typical meadow than that in marsh meadow.

Keywords biomass, nitrogen and phosphorus nutrition, structure dynamics, Sanjiang Plain

Translated from *Chinese Journal of Applied Ecology*, 2006, 17(2): 221–228 [译自: 应用生态学报]

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1 Introduction

Nutrient element cycling was an important study field of modern wetland ecology (William and James, 1993; Zhang and Xu, 1997). In general, nitrogen (N) and phosphorus (P) are the most important nutrient elements in the wetland ecosystem, which have critical influence on many ecological processes. Research on the structure dynamics of N and P has laid the important basis for their cycling study, which can, to some extent, help to understand the ecological processes and functions of wetland ecosystem (Woodmansee and Duncan, 1980). At present, many relative studies on the dynamics of N and P in wetland plant were widely reported in overseas research field. Margaret and Anne (1999) studied the distribution and bioaccumulation characteristics of N and P in different organs of plants in nine constructed wetlands of Queensland. Romero et al. (1999) studied the interactive effects of N and P on growth, nutrient allocation and ammonium nitrogen (NH_4^+-N) uptake kinetics of *Phragmites australis*. Xie et al. (2004) studied the growth, nutrient distribution and resource allocation of water hyacinth as affected by different N and P nutrient conditions. Bent et al. (2001) also studied the growth, biomass allocation and N-use efficiency in *Cladium jamaicense* and *Typha domingensis* as affected by phosphorus and oxygen availability. In domestic research fields, Zhu et al. (2000) studied the N bioaccumulation characteristics in *Phragmites australis* in Pajin wetland. He (2002) and Sun et al. (2000) also studied the dynamics of N in *Calamagrostis angustifolia* and *Carex lasiocarpa* in growing period, respectively. In general, the information on the nutrient dynamics of N and P in wetland plant, and the response of plant to the changes of N and P nutrient status were limited in current domestic research field.

The Sanjiang Plain is one of the biggest regions, where wetland is widely distributed and the types of wetland are various, in China. Generally, marsh meadow and marsh are the main vegetation types in the region, and *C. angustifolia* formation is widely distributed in marsh meadow. *C. angustifolia* formation mainly includes both *C. angustifolia* typical meadow and *C. angustifolia–Carex* marsh meadow (He, 2000), which accounts for 34.45% of total wetland area. The two types of *C. angustifolia* are located in different water gradients, which are sensitive to the changes of water conditions. At present, the information on the comparison of biomass structure and N, P nutrient status of *C. angustifolia* in different water gradient is still scarce. In this paper, the biomass structure and N, P nutrient status of *C. angustifolia* in different communities were systemically studied, and the results could help to understand the forming process of productivity and the absorption status of N and P. In addition, the results also could provide the basis data for the study of nutrient material cycling and energy flow in the two types of *C. angustifolia* wetlands.

2 Study site and methods

2.1 Study site

The study was carried out in experimental field at Ecological Experiment Station of Mire Wetland in the Sanjiang Plain, the Chinese Academy of Sciences (latitude 47°35′N, longitude 133°31′E), located in the northeast of Heilongjiang Province in China. The experimental field is located in river terrain between Bielahong River and Nongjiang River. It is at 55.4–57.0 m elevation and the total area is about 100 hm^2. The site is of typical continental monsoon climate, summer is warm and rainy while winter is long-term cold. Annual average temperature is 1.9°C and the valid cumulative temperature is about 2,300°C. The distribution of precipitation is odds in a year. The annual average precipitation is about 600 mm, and approximate 60% of it occurs between June and September. The physiognomy type of experimental field is depressional wetland which is the most typical distribution in the Sanjiang Plain. From centre to outside, the main vegetations of depressional wetland are circularly distributed with *Carex pseudocuraica*, *Carex lasiocarpa*, *Carex meyeriana* and *C. angustifolia*, etc. The soils are predominated by meadow marsh soil, humus marsh soil and gley baijiang soil.

2.2 Composition of *C. angustifolia* wetland community

The *C. angustifolia* wetland is predominated by *C. angustifolia* population, and the coverage of it in *C. angustifolia* typical meadow community and *C. angustifolia–Carex* mash meadow community is larger than 83% and 77%, respectively (Ji, 2004). In general, the accompanying species in *C. angustifolia* typical meadow community mainly include *Salix myrtilloides*, *Spiraea salicifolia*, *Sium suave*, *Gentiana scabra* and *Iris laevigata*, etc. While in *C. angustifolia-Carex* mash meadow community, the accompanying species mainly include *Carex Lasiocarpa*, *Carex pseudocuraica*, *Glyceria acutiflora*, *Equisetum limosum*, *Salix brachypoda* and *Sium suave* var. *angustifolium*, etc. In this study, only the *C. angustifolia* biomass and its N and P nutrient dynamics were determined, while the values of accompanying species were ignored for the proportions of their biomass in the two types of *C. angustiflolia* communities are much lower (0.2%–4.5% and 2.3%–12%, respectively).

2.3 Methods

This study was carried out *in situ* from May to October in 2004. Each plot (15 m × 15 m), before experiment, was laid in *C. angustifolia* typical meadow community and *C. angustifolia-Carex* mash meadow community, respectively. The aboveground biomass was determined by harvest method and the sampling frequency was about 15 days, which was based on the growth characteristic of plant. When sampling, three or four quadrats (25 cm × 25 cm) were randomly selected in the plot of each community. The aboveground part of plant was clipped near the ground with a scissor, and *C. angustifolia* were separated in the laboratory according to vegetation types and stem, leaf and vagina. The belowground biomass was determined by dig method, and the sampling frequency was in accordance with aboveground biomass. Two or three determination subplots of aboveground biomass in the plot of each community were randomly selected, and then the root was dug out (sampling depth of 50 cm). The root was carefully washed, and *C. angustifolia* were also separated in the laboratory according to the root types and the dead or live root. All plant samples were oven-dried at 80°C for 24 h, weighed and ground (<0.85 mm) using a Wiely mill and analyzed for total nitrogen using the semi-micro Kjedahl technique. The total phosphorus was analyzed by molybdate-ascorbic acid colorimetry (H_2SO_4-H_2O_2 digestion). Two grams of plant sample was prepared in triangle bottle, and 10 mL of 17% MgO was injected. Then the triangle bottle was put into an exsiccator at 40°C for 5–6 h. Finally, the bottle was taken out and the ammonium nitrogen (NH_4^+-N) content was determined by titration method of standard acid. The plant sample was lixiviated by water, and the ratio of sample to water was 1 : 10. After shaking for 1 h, 1 mL of lixivium was taken out to determine the nitrate nitrogen (NO_3^--N) content by sulfosalicylic acid method.

2.4 Statistical analysis

The samples were presented as means over the replications. The Origin 7.5 and SPSS 11.0 software were applied in basic statistical analysis and mathematical simulation.

3 Results and discussion

3.1 Biomass

3.1.1 Aboveground biomass and its structure

The aboveground biomass of the two types of *C. angustifolia* had significantly seasonal dynamics in growing season

(Fig. 1). Both of them increased since the last ten-days of April with the improvement of hydrothermal condition, and the maximum values were observed on July 29 (1,066.86 g/m^2) and August 14 (706.71 g/m^2), respectively. Since then, the aboveground biomass declined gradually as the coming of autumn and the decrease in temperature (the aboveground part gradually withered), and the minimum values (547.33 and 491.91 g/m^2) were observed on October 12 as the temperature was much lower. In general, both the seasonal dynamics of aboveground biomass of the two types of *C. angustifolia* presented single peak changing, and the growth curves of single peaks were just in accordance with the characteristics of monsoon climate in the region. In growing season, the aboveground biomasses of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia* (1.11–2.09 folds), and the maximum value of the latter occurred 15 days later, which might be correlated with the differences of physiological characteristics and habitats. Ji (2004) found that the habitat, with seasonal standing water, had significantly effect on the growth of *C. angustifolia* community. The vegetation height and coverage of typical meadow *C. angustifolia* (no standing water) were much larger than those of marsh meadow *C. angustifolia* (with seasonal standing water), and the *C. angustifolia* was more adaptive to grow in the habitat of no standing water. In addition, the leaf, vagina and stem biomass of the two types of *C. angustifolia* also presented single peak changing, and the maximum values (417.55, 228.96, 435.34 and 267.01, 157.45, 314.87 g/m^2, respectively) were observed between July 14 and August 14. Comparatively, the leaf, vagina and stem biomass of typical meadow *C. angustifolia* were also much higher than those of marsh meadow *C. angustifolia*, and the maximum values of the latter also occurred about 15 days later.

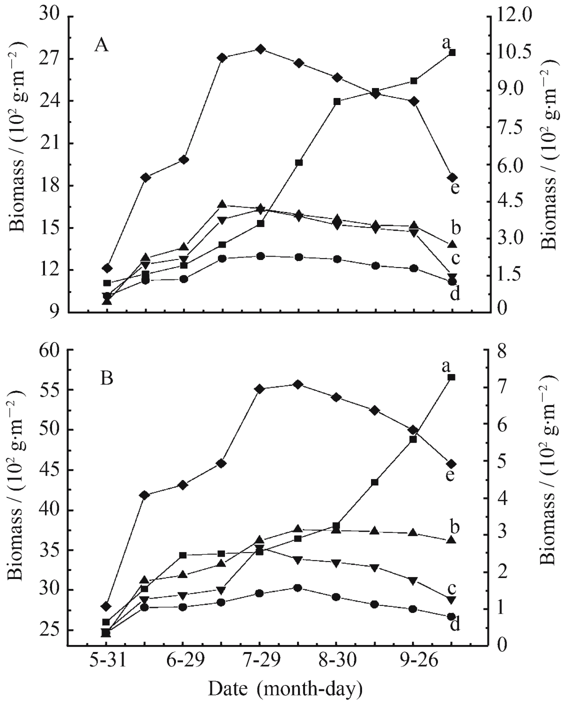

Fig. 1 Seasonal dynamics of the biomass of *Calamagrostis angustifolia* in the two types of wetland communities. A: Ass. *Calamagrostis angustifolia* typical meadow; B: Ass. *Calamagrostis angustifolia*-*Carex* sp. marsh meadow; a: root; b: stem; c: leaf; d: vagina; e: aboveground biomass. The same below.

The *F*/*C* value is the ratio between the biomass of assimilation organs (*F*) and non-assimilation organs (*C*) of vegetation population, which is an important index to represent the photosynthesis of vegetation (Ni et al., 1998). The change characteristics of *F*/*C* values of the two types of *C. angustifolia* were basically the same. Both of them got hypo-maximum values on June 19 (correlated with the branch of plant and the increase amount of leaf), and slightly declined afterward (correlated with the increase amount and accumulation amount of stem which were larger than those of leaf). Since then, the values rapidly increased, and the maximum values were observed on July 16 (0.649) and July 29 (0.635), respectively (correlated with the increase amount and accumulation amount of leaf which rapidly increased during the second growth peak). After that, the *F*/*C* values decreased, and slightly fluctuated before September 26 due to the decline of photosynthesis and the senescence of leaf. After September 26, the values rapidly decreased with the increase in litter (Table 1). Nichiporovich (1959) considered that the ratio between the net production (ΔP_N) and total production (ΔP_T) of vegetation population could be used to measure the material production efficiency of photosynthesis (Jiang et al., 1985; Zhu and Jia, 1996). In general, the larger the ratio is, the higher the production efficiency is. As ΔP_N is the deficit of ΔP_T and ΔR ($\Delta P_N = \Delta P_T - \Delta R$) and ΔR is in direct proportion with C, the lower ΔR is, the higher $\Delta P_N / \Delta P_T$ ratio is. In growing season, the *F*/*C* values of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia*, which indicated that the material production efficiency of photosynthesis for the former was much higher than that for the latter. The results of mathematical simulation showed that the biomass of aboveground part and each organ all could be described by $Y = A + B_1t + B_2t^2 + B_3t^3$, where Y is biomass, A constant, B_1, B_2 and B_3 coefficients, and t growth days (Table 2).

3.1.2 Belowground biomass

The belowground biomass of the two types of *C. angustifolia* also had significantly seasonal dynamics (Fig. 1). In general, the minimum values were observed on May 31, since then, they increased at all times and achieved the maximum values (2,744.73 and 5,658.07 g/m^2) on October 12. The minimum values observed on May 31 were mainly correlated with the respiration consumption of nutrient in long winter and the supply of nutrient to the growth of plant in the second year. At initial stage, the nutrients were largely transferred from belowground to aboveground to meet the need of growth. In addition, the senescence and decay of root also could partly explain the minimum belowground biomass observed on May 31. In growing season, with the growth of plant, the organic

Table 1 Dynamics of the F/C values of the two types of *C. angustifolia*

Communities	Date (month-day)									
	5–31	6–19	6–29	7–16	7–29	8–14	8–30	9–12	9–26	10–12
Ass. *Calamagrostis angustifolia* typical meadow	0.637	0.573	0.549	0.649	0.643	0.628	0.599	0.628	0.616	0.375
Ass. *Calamagrostis angustifolia–Carex* sp. marsh meadow	0.612	0.552	0.497	0.487	0.635	0.522	0.510	0.508	0.443	0.348

Table 2 Simulation models of aboveground biomass and each organ biomass of the two types of *C. angustifolia*

Communities	Item	Regression equation	R	p
Ass. *Calamagrostis angustifolia* typical meadow	Root	$Y = 1,356.476,84 - 306.481,82t + 102.928,98t^2 - 5.882,42t^3$	0.991,5	$p < 0.000,1$
	Stem	$Y = -684.780,67 + 23.855,05t - 0.161,58t^2 + 0.000,322,201t^3$	0.974,1	$p < 0.001$
	Leaf	$Y = -281.876,34 + 9.093,25t - 0.006,02t^2 - 0.000,185,435t^3$	0.967,8	$p < 0.001$
	Vagina	$Y = -140.123,11 + 5.824,12t - 0.019,16t^2 - 0.000,033,718,9t^3$	0.971,3	$p < 0.001$
	Aboveground	$Y = -1,106.780,13 + 38.772,42t - 0.186,76t^2 + 0.000,103,047t^3$	0.972,8	$p < 0.001$
Ass. *Calamagrostis angustifolia-Carex* sp. marsh meadow	Root	$Y = 1,930.849,4 + 831.194,93t - 157.482,54t^2 + 11.215,41t^3$	0.996,9	$p < 0.000,1$
	Stem	$Y = -292.159,34 + 10.295,47t - 0.053,03t^2 - 0.000,073,844,5t^3$	0.987,8	$p < 0.000,1$
	Leaf	$Y = -124.726,56 + 4.113,06t + 0.005,44t^2 - 0.000,122,274t^3$	0.945,5	$p < 0.01$
	Vagina	$Y = -147.609,32 + 6.025t - 0.037,04t^2 - 0.000,055,841,2t^3$	0.962,2	$p < 0.001$
	Aboveground	$Y = -564.495,23 + 20.433,5t - 0.084,62t^2 - 0.000,007,412,02t^3$	0.975,7	$p < 0.001$

matters formed by photosynthesis were largely transferred from aboveground to belowground, which induced the belowground biomass gradually increased until the end of growing season. In contrast with aboveground biomass, the belowground biomasses of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia* (1.59–2.78 folds), and the difference between them was significant ($p < 0.01$). Some relative studies indicated that soil water, cumulative temperature, precipitation, ground temperature and soil organic matter had significant effect on belowground biomass (Gao and Hu, 1990; Wang et al., 1998; Yu and Yu, 2001). In this study, as the two types of *C. angustifolia* were located in different water gradients of the same plot, the differences of atmospheric temperature, ground temperature and precipitation between them were not significant, and they were not the main factors that affected belowground biomass, while the significant differences of ecological characteristic, water condition, soil water content and organic matter content between them might be the important reasons. The results of mathematical simulation showed that the belowground biomass of the two types of *C. angustifolia* also could be described by $Y = A + B_1t + B_2t^2 + B_3t^3$ (Table 2).

3.1.3 Composition of total biomass

In growing season, both the percentages of aboveground biomass in total biomass of the two types of *C. angustifolia* increased initially and decreased afterward, while the changes of the values of belowground biomass in total biomass were just adverse (Table 3). Comparatively, the percentages of aboveground biomass in total biomass of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia*, while the values of belowground biomass in total biomass of the former were much lower than those of the latter. In addition, both the maximum ratios of aboveground biomass and belowground biomass of the two types of *C. angustifolia* were observed in growth midseason, and the value of typical meadow *C. angustifolia* was much higher than that of marsh meadow *C. angustifolia*, which indicated that the carbon fixation capacity of aboveground part of the former was larger than that of the latter, while the capacity of belowground part of the former was lower than that of the latter. The seasonal changes of total biomass and the composition relationship among different organs of the two types of *C. angustifolia* were simulated by mathematical methods, and the results were as follows.

Table 3 Percentages of aboveground and underground biomass in total biomass of the two types of *C. angutifolia*

Communities	Item	Date (month-day)					
		5–31	6–29	7–29	8–30	9–26	10–12
Ass. *Calamagrostis angustifolia* typical meadow	Aboveground /%	13.99	33.40	41.08	28.43	25.20	16.63
	Belowground /%	86.01	66.60	58.92	71.57	74.80	83.37
	Aboveground/belowground	0.163	0.502	0.697	0.397	0.337	0.199
Ass. *Calamagrostis angustifolia–Carex* sp. marsh meadow	Aboveground /%	3.98	11.25	16.65	15.00	10.69	8.00
	Belowground /%	96.02	88.75	83.35	85.00	89.31	92.00
	Aboveground/belowground	0.041	0.126	0.200	0.176	0.120	0.087

Total biomass of typical meadow *C. angustifolia*:

$$Y = 1{,}171.107{,}15 - 11.952{,}89t + 0.447{,}5t^2 - 0.001{,}78t^3 \quad (R = 0.997{,}7, p < 0.000{,}1)$$

Total biomass of marsh meadow *C. angustifolia*:

$$Y = -411.459{,}36 + 113.141{,}04t - 1.004{,}03t^2 + 0.003{,}31t^3 \quad (R = 0.996{,}5, p < 0.000{,}1)$$

Composition relationship among different organs of typical meadow *C. angustifolia*:

$$V = 34.279 + 0.000{,}590{,}9R + 0.137S + 0.328L \quad (R = 0.991, p < 0.001)$$

Composition relationship among different organs of marsh meadow *C. angustifolia*:

$$S = -174.138 + 0.056{,}91R + 0.506L + 1.305V \quad (R = 0.992, p < 0.001)$$

where Y is total biomass, t is growth days, and R, S, L and V are root, stem, leaf and vagina, respectively. In general, the fitting precision of the above-mentioned equations was much higher, which could be used to simulate the changes of total biomass and the composition relationships among different organs.

3.2 Dynamics of nitrogen nutrient

In the growing season, both the total nitrogen (TN) contents in different organs of typical meadow *C. angustifolia* and marsh meadow *C. angustifolia* had significantly seasonal dynamics due to the differences of their growth periods and tissue structures. In general, the change trend of TN content in aboveground organs of the two types of *C. angustifolia* was basically the same, the maximum values were observed on May 31, and then, the values declined gradually as the lapse of time, and the minimum values were observed at the end of growing season (Fig. 2). Compared with the latter, the changes of TN contents of the former fluctuated greatly, which was mainly correlated with the "dilute effect" caused by the increase in aboveground biomass (Chen, 1997). The aboveground biomass of the former increased much faster than that of the latter. Therefore, the "dilute effect" of the former was much higher than that of the latter. Further analysis showed that the changes of TN contents in leaf, vagina and stem of the two types of *C. angustifolia* had no significant difference ($p > 0.05$). In addition, both the distribution characteristics of TN contents in aboveground organs of the two types of *C. angustifolia* were basically the same, with the order of leaf > vagina > stem, which indicated that leaf and vagina were the main N accumulation organs. Comparatively, the TN contents in stem changed smoothly except that some fluctuations were observed before the middle ten-days of June, and the means were 2,789.06 ± 153.40 mg/kg and 2,796.60 ± 219.91 mg/kg, respectively. If the TN content was used to reflect N utilization status, the higher the value was, the lower the utilization rate was. The standard was applied to evaluate the N utilization rates of different organs, and the results showed that both the two types of *C. angustifolia* presented the order of stem > vagina > leaf, which also indicated that leaf and vagina were the main N accumulation organs. In general, the changes of TN contents in roots of the two types of *C. angustifolia* were basically the same, with one obvious peak on June 29 and July 29, respectively (Fig. 2). In contrast with that, the maximum aboveground biomass was observed on July 29 and August 14, respectively (Fig. 1), which indicated that the root must accumulate enough N nutrient before the coming of growth midseason to meet the need of growth. Since then, the TN contents declined due to the N nutrients were largely transferred from belowground to aboveground, and the minimum values were observed on July 29 and August 30, respectively. After July 29 or August 30, the TN contents increased rapidly due to the translocation of N nutrients from aboveground to belowground as the senescence of aboveground parts, and the maximum values were observed at the end of growing season. In general, the TN contents in root of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia*, but there was no significant difference between them ($p > 0.05$). Comparatively, the TN contents in root fluctuated greatly, which indicated that root was the important distributing center of N, and it had dramatic significance to the N supply of aboveground part.

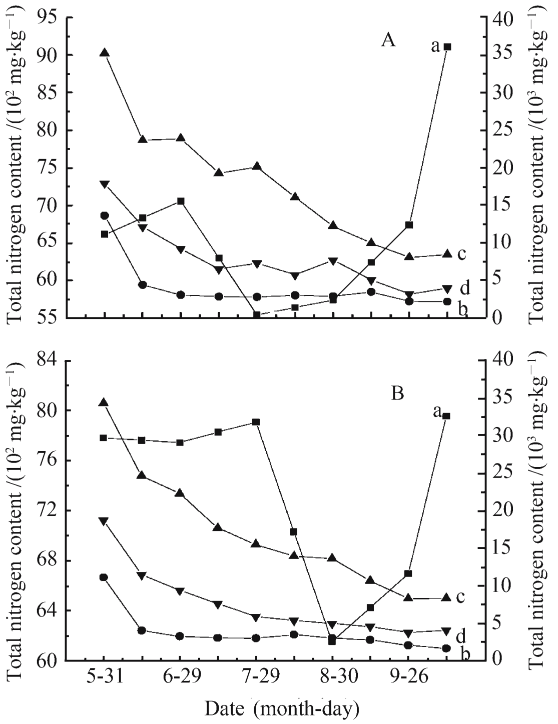

Fig. 2 Changes of total nitrogen content in each part of the two types of *C. angustifolia*. A: Ass. *Calamagrostis angustifolia* typical meadow; B: Ass. *Calamagrostis angustifolia–Carex* sp. marsh meadow.

The changes of NH_4^+-N contents in different organs of the two types of *C. angustifolia* were basically the same (Fig. 3). The values of leaf and vagina presented double peak changing, while the values of stem changed complicatedly. In general, the values of stem declined at all times before August 30. Since then, the values rapidly increased and the peaks were observed on September 12. After that, the values declined, and had no great fluctuations at the end of growing season. The values of root, on the whole, presented the shape of "W", and the lower values were observed on June 29 and September 12, respectively. Comparatively, the two lower values of root were observed at the same time with not only the two peaks of leaf, vagina but also the peak of stem, which indicated that the close relationship between root and aboveground organs on the nutrient supply. In contrast with NH_4^+-N, although the changes of NO_3^--N contents in different organs of the two types of *C. angustifolia* were similar, some significant differences still existed. In general, both the values of root of the two types of *C. angustifolia* increased initially and decreased afterward, and the slight increase was also observed at the end of growing season, but the changes of marsh meadow *C. angustifolia* were more significant. Moreover, the changes of the values of stem and vagina of typical meadow *C. angustifolia* were basically the same, which presented the shape of "W". In contrast with that, the changes of the values of stem and vagina of marsh meadow *C. angustifolia* were basically the same before July 29, and the adverse changes were observed between July 29 and October 12. Comparatively, the changes of the values of leaf and vagina of marsh meadow *C. angustifolia* and the values of leaf of typical meadow *C. angustifolia* were basically the same, they all increased initially and decreased afterward, and the rapid increases were observed at the end of growing season.

The changes of N content in different organs of the two types of *C. angustifolia* were mainly correlated with environmental factors, the supply status of N, the structure characteristic and growth rhythm of plant. In general, the NH_4^+-N contents in different organs in June were much higher, which were correlated with the strong absorption capacity as the plant was in bloom. In contrast with that, the changes of NO_3^--N contents in different organs of the two types of *C. angustifolia* had significant differences, which might be correlated with the bioecology characteristics, the absorption and utilization status of NO_3^--N, and the intensity of nitrification in different organs. The TN contents and NH_4^+-N contents in different organs of the two types of *C. angustifolia*, on the whole, declined in the phase from July to August, while the NO_3^--N contents in different organs increased initially and decreased afterwards except that the values in stem of marsh meadow *C. angustifolia* increased at all times. As the two types of *C. angustifolia* were in heading stage which needed lots of N nutrient, and the effective N in soil was limited which could not meet the need of plant growth, the rapid decrease in TN contents and NH_4^+-N contents in different organs were mainly correlated with the

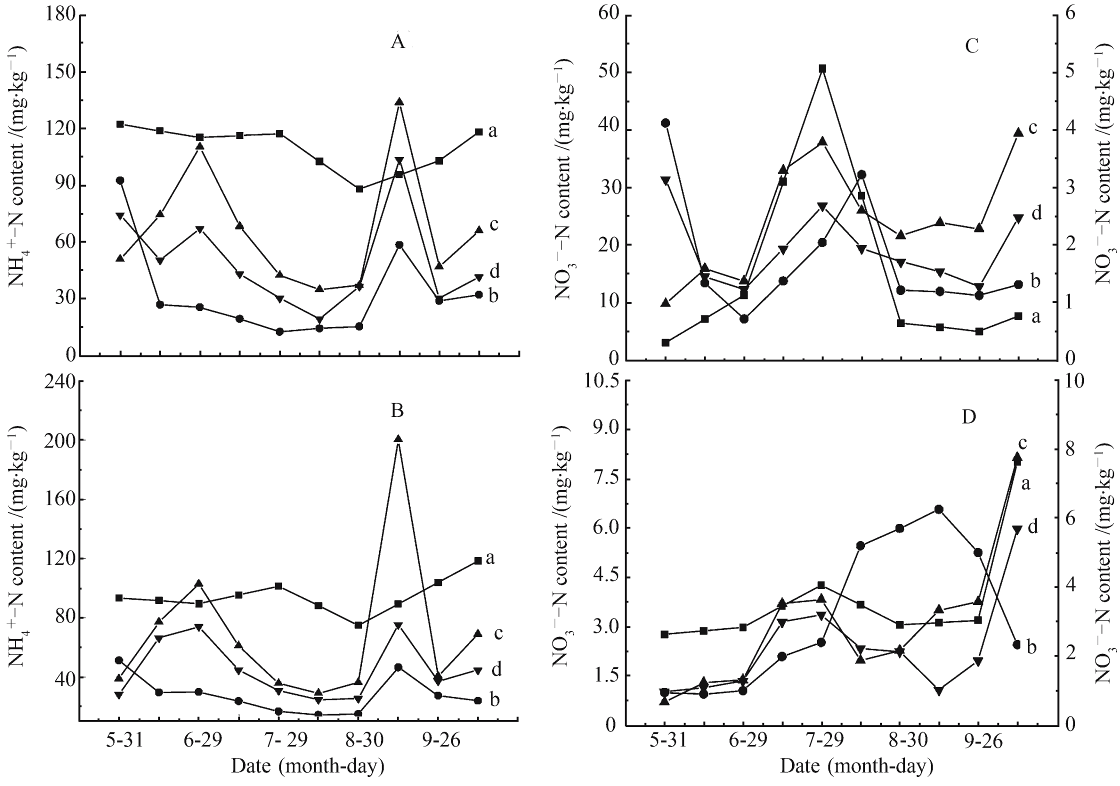

Fig. 3 Changes of NH_4^+-N and NO_3^--N contents in each part of the two types of *C. angustifolia.*
A: NH_4^+-N content in Ass. *Calamagrostis angustifolia*; B: NH_4^+-N content in Ass. *Calamagrostis angustifolia–Carex* sp.; C: NO_3^--N content in Ass. *Calamagrostis angustifolia*; D: NO_3^--N content in Ass. *Calamagrostis angustifolia–Carex* sp.

translocation of N from root, stem, leaf and vagina to ear. In contrast with that, the changes of NO_3^--N contents might be correlated with the absorption and utilization status of NO_3^--N and the intensity of nitrification in different organs. After the last ten days of August, the NH_4^+-N contents in aboveground organs of the two types of *C. angustifolia* increased again and rapidly decreased afterwards, and had no great fluctuations at the end of growing season, while the values of root increased at all times. In contrast with that, the NO_3^--N contents in different organs presented some fluctuations and increased at the end of growing season except the values in stem of marsh meadow *C. angustifolia* decreased at all times. The increase in NH_4^+-N contents in aboveground organs from August 30 to September 12 might be correlated with the decrease oin requirement and the weakening of assimilation of NH_4^+-N, the reinforcement of N mineralization in different organs and the increase in NH_4^+-N contents in soil. After that, the rapid decrease in NH_4^+-N contents in aboveground organs and the increase in NH_4^+-N contents in root were mainly correlated with the translocation of N from aboveground organs to root. In contrast with that, the changes of NO_3^--N contents in different organs, from August 30 to October 12, might be correlated with the reinforcement of nitrification, the decrease in requirement and the translocation degree of NO_3^--N. In general, the NH_4^+-N contents in different organs of the two types of *C. angustifolia* were much higher than NO_3^--N contents, with $NH_4^+\text{-N}/NO_3^-\text{-N} > 1$. If the dissimilation reduction of NO_3^--N and the assimilation or nitrification of NH_4^+-N were not considered, the NH_4^+-N and NO_3^--N contents in root might reflect the absorption status of plant. The results indicated that the absorption capacity of typical meadow *C. angustifolia* was larger than that of marsh meadow *C. angustifolia*, which might be correlated with the ecological characteristics and the different habitats.

3.3 Dynamics of phosphorus nutrient

In growing season, the total phosphorus (TP) contents in different organs of the two types of *C. angustifolia* also had significantly seasonal changes. Similar with the change of TN contents, the maximum values of TP contents were observed on May 31, and then, the values, on the whole, declined gradually as the lapse of time, and the minimum values were observed at the end of growing season (Fig. 4). In general, the TP contents in aboveground organs fluctuated greatly, and the reason also might be correlated with the "dilute effect" caused by the increase in aboveground biomass. Comparatively, the TP contents in aboveground organs of typical meadow *C. angustifolia* were much higher than those of marsh meadow *C. angustifolia*, but there was no significant difference between them ($p > 0.05$). Moreover, the distribution characteristics of TP contents in aboveground organs were similar with those of TN contents, with the order of leaf > vagina > stem, which was closely correlated with the structures and functions of different organs. As leaf was the assimilation organ of plant with faster metabolism rate, the contents of TN and TP in it were much higher than those of other aboveground organs. In addition, as *C. angustifolia* was gramineae herbaceous plant and the photosynthesis also could be carried out in vagina and stem (Yang et al., 2001), the contents of TN and TP in vagina and stem were also much higher.

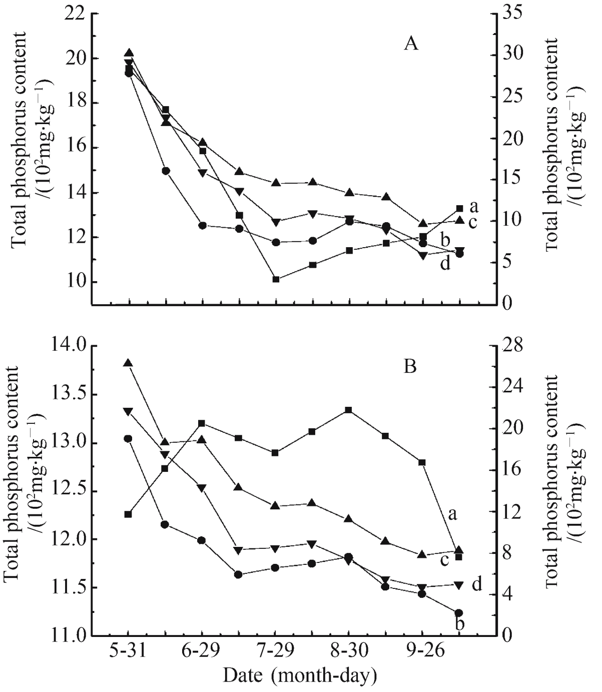

Fig. 4 Changes of total phosphorus content in each part of the two types of *C. angustifolia*. A: Ass. *Calamagrostis angustifolia* typical meadow; B: Ass. *Calamagrostis angustifolia–Carex* sp. marsh meadow.

Similar with the representation means of N utilization status, the TP content was used to reflect the P utilization status of aboveground organs, and the results showed that both the two types of *C. angustifolia* presented the order of stem > vagina > leaf. In general, the TP contents in roots of typical meadow *C. angustifolia* and marsh meadow *C. angustifolia* had significant difference. The change of the values of the former presented the shape of "V", which gradually decreased before July 29 and increased afterwards. Comparatively, the change trend of TP contents of the former, after June 29, was similar with that of TN contents, and the correlation between them was positive ($r = 0.589$, $n = 8$). In growth midseason, the P in root was largely transferred from belowground to aboveground to meet the need of plant growth. Since then, the P contents in root increased gradually due to the translocation of P nutrient from aboveground to belowground as the senescence of aboveground parts, which indicated that P was also an important factor affecting the growth of the former. In contrast with that, the change of the values of the latter presented the shape of "M", and two peaks were observed on June 29 and August 30, respectively. Comparatively, the change trend of TP contents of the latter, in growing season, was different with that of TN contents, and the correlation between them was negative ($r = -0.527$,

$n = 10$). In addition, the results analyzed previously showed that the change of TN contents in root had better synchronism with its growth rhythm, which indicated that N was the important limiting nutrient affecting the growth of the latter. As the change of TP contents in root had worse synchronism with its growth rhythm and the correlation between them was negative, it only had influence on the growth of the latter to some extent. The changes of TP contents in root of the latter might be correlated with the absorption status of P in different growth phases.

3.4 Dynamics of nitrogen and phosphorus storages

In different growth phases, the biomasses and N, P contents of different organs of the two types of *C. angustifolia* had significant difference, which induced the differences of N and P storages in different organs between them (Fig. 5). In general, the N storages in aboveground organs gradually increased from May 31, and the maximum values were observed in growth midseason. Since then, the values decreased at all times as the senescence of aboveground organs and the translocation of N from aboveground to belowground. Comparatively, the N storages in stem and vagina of typical meadow *C. angustifolia* varied in flexuosity, which was more significant than that of marsh meadow *C. angustifolia*. Moreover, both the changes of N storage in leaf of the two types of *C. angustifolia* presented single peak changing, while that of the former was more significant. The changes of N storage in root of the two types of *C. angustifolia* were basically the same. The values increased at all times except that one obvious valley was observed on July 29 and August 30, respectively, because the N nutrients in root, in growth midseason, were largely transferred to aboveground part. Overall, the N storages in different organs of the two types of *C. angustifolia*, in growth stage, presented the order of root > leaf > vagina > stem. While in maturing stage, the order was root > leaf > stem > vagina, which indicated that N was mainly stored in root. Comparatively, the N storages in leaf and vagina fluctuated greatly (the values were 4,596.11 ± 2,258.06, 2,566.42 ± 984.52 and 1,211.77 ± 422.23, 732.80 ± 276.96 mg/m^2, respectively), while that of stem fluctuated smoothly, which might be correlated with the growth characteristics of aboveground organs. As leaf and vagina were the organs that most likely to fade, the N nutrient in them would be gradually transferred before senescence. Adversely, the stem seldom faded during the growth process. Similar with the changes of N storage, both the P storages in aboveground organs of typical meadow *C. angustifolia* and marsh meadow *C. angustifolia* also varied in flexuosity, which presented multi-peaks, and the change of the former was more significant than that of the latter. Comparatively, the change of P storage in root of the former was similar to that of TP content, which presented the shape of "V", while that of the latter increased at all times. In conclusion,

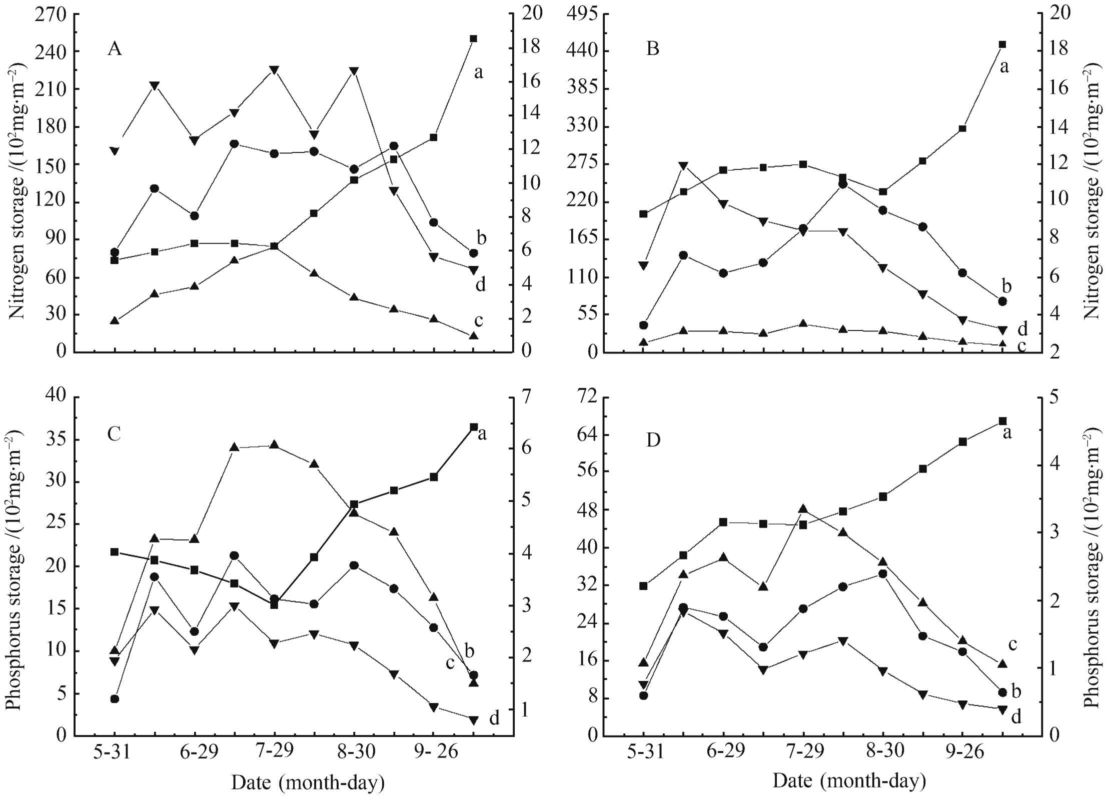

Fig. 5 Changes of nitrogen and phosphorus storages in each part of the two types of *C. angustifolia*.
A: Nitrogen storage in Ass. *Calamagrostis angustifolia*; B: Nitrogen storage in Ass. *Calamagrostis angustifolia–Carex* sp.; C: Phosphorus storage in Ass. *Calamagrostis angustifolia*; D: Phosphorus storage in Ass. *Calamagrostis angustifolia–Carex* sp.

Table 4 Dynamics of N/P ratios of different organs of the two types of *C. angustifolia*

Communities	Item	Date (month-day)										Means
		5–31	6–19	6–29	7–16	7–29	8–14	8–30	9–12	9–26	10–12	
Ass. *Calamagrostis angustifolia* typical meadow	Root	3.38	3.86	4.45	4.85	5.48	5.24	5.03	5.32	5.60	6.86	5.01 ± 0.31
	Stem	4.89	2.73	3.22	3.11	3.75	3.93	2.87	3.66	2.98	3.53	3.47 ± 0.20
	Leaf	11.66	10.85	12.29	12.12	13.84	10.97	9.15	7.74	8.39	8.41	10.54 ± 0.64
	Vagina	6.14	5.40	5.81	4.74	7.33	5.24	7.43	5.65	5.32	6.02	5.91 ± 0.28
Ass. *Calamagrostis angustifolia-Carex* sp. marsh meadow	Root	6.35	6.10	5.87	6.00	6.13	5.36	4.61	4.92	5.23	6.73	5.73 ± 0.21
	Stem	5.84	3.77	3.53	5.18	4.58	4.97	4.00	5.88	5.02	7.41	5.02 ± 0.37
	Leaf	13.06	13.22	11.80	12.39	12.38	10.93	12.11	11.71	10.70	10.07	11.84 ± 0.32
	Vagina	8.62	6.53	6.56	9.15	6.96	6.02	6.75	8.25	7.90	8.17	7.49 ± 0.33

the P storages in different organs of the two types of *C. angustifolia*, in growing season, presented the order of root > leaf > stem > vagina, which was similar to that of N storages.

3.5 Limiting status of nitrogen and phosphorus nutrients

The supply status of nitrogen and phosphorus is significant to the primary production of plant in wetland ecosystem. Koerselman and Meuleman (1996) found that the growth of plants (in fresh marsh of Europe) would be limited by nitrogen if the N/P ratios were less than 14. If the N/P ratios were between 14 and 16, they would be limited by both nitrogen and phosphorus. If the N/P ratios were larger than 16, they would be limited by phosphorus. The conclusion was used to discuss the N/P ratio of *C. anguisfolia*, the growth conditions of which were similar with those above-mentioned plants in Europe. The results showed that the average N/P ratios of typical meadow *C. angustifolia* and marsh meadow *C. angustifolia* were 5.76 ± 0.28 and 5.99 ± 0.20, respectively (Table 4), which indicated that both of them were limited by nitrogen. And the conclusion was just in accordance with the results analyzed previously (3.3), which confirmed the validity of N/P ratios. The study of N/P ratios of different organs, in different phases, showed that both the changes of N/P ratios of the two types of *C. angustifolia* had significant seasonality, which was correlated with the absorption and utilization status of N and P in different organs and the supply status of N and P in soils. In general, both the N/P ratios of different organs of the two types of *C. angustifolia* presented the order of leaf > vagina > root > stem. Comparatively, the average N/P ratios of plant and different organs of marsh meadow *C. angustifolia* were much higher than those of typical meadow *C. angustifolia*, which indicated that the limitation degree was higher in the former than that in the latter.

4 Conclusions

The following four conclusions have been drawn from the systemic study of biomass structure and N, P nutrient of typical meadow *C. angustifolia* and marsh meadow *C. angustifolia*. (1) The biomass of aboveground part and each organ presented single peak changing, with the maximum value of the latter occurred 15 days later. The aboveground biomasses of the former were much higher than those of the latter (1.11–2.09 folds), while the belowground biomasses of the latter were much higher than those of the former (1.59–2.78 folds). The dynamics of F/C values of the two types of *C. angustifolia* were basically the same, and they were all less than 1. They were bigger in typical meadow than those in marsh meadow, which indicated that the material production efficiency of photosynthesis of the former was much higher. The biomass of different *C. angustifolia* organs in the two types of wetland communities all could be described by $Y = A + B_1t + B_2t^2 + B_3t^3$. (2) The total N and P contents in different organs of aboveground part all descended monotonically in the growing season, with the order of leaf > vagina > stem. The change of total N content in roots of the two types of *C. angustifolia* was consistent, while that of total P was quite different. The content of TN, NH_4^+-N and NO_3^--N, especially of NH_4^+-N and NO_3^--N, varied widely in different organs, with $NH_4^+\text{-N}/NO_3^-\text{-N} > 1$, which was correlated with the growth rhythm of plant, the N supply status of soil and the N chemical transformation in plant etc. (3) The N storages in different organs of the two types of *C. angustifolia*, in growing stage, presented the order of root > leaf > vagina > stem, while in maturing stage, the order was root > leaf > stem > vagina. Similar with that, the P storage of different organs presented the order of root > leaf > stem > vagina in growing season. Root was the important storage of N and P, but the storage of N and P in stem, leaf and vagina fluctuated greatly. (4) The N/P ratios of the two types of *C. angustifolia* were all less than 14, which implied that N might be the limiting nutrient of *C. angustifolia*. Both the N/P ratios of different organs of the two types of *C. angustifolia* presented the order of leaf > vagina > root > stem. The average N/P ratios of plant and different organs of marsh meadow *C. angustifolia* were much higher than those of typical meadow *C. angustifolia*, which indicated that the limitation degree was higher in typical meadow than that in marsh meadow.

Acknowledgements The authors acknowledge the financial support of the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX3-SW-332) and the National Natural Science Foundation of China (Grant No. 90211003). We thank Dr. Zhou Wangming and Dr. Zhao Wei for their friendly helps.

References

Bent L, Hans B, Irving A M (2001). Growth, biomass allocation and nutrient use efficiency in *Cladium jamaicense* and *Typha domingensis* as affected by phosphorus and oxygen availability. Aquat Bot, 70: 117–133

Chen L Z (1997). Nutrient Cycling of Forest Ecosystem in China. Beijing: China Meteorological Press, 1–182 (in Chinese)

Gao Q S, Hu Z J (1990). A study of phytomass and solar energy conversion rate for of underground pary in sainfoin. Pratac Sci, 7(1): 25–29 (in Chinese)

He C Q (2002). Distribution and the correlativity of plant element in *Carex lasiocarpa* wetland. Chin J Ecol, 21(1): 10–13 (in Chinese)

He L (2000). Sanjiang Plain in China. Harbin: Heilongjiang Science and Technology Press (in Chinese)

Ji Y H (2004). The change characteristic of species diversity of typical wetland plant community in the Sanjiang Plain. Master degree dissertation. Changchun: Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences (in Chinese)

Jiang S, Qi Q H, Kong D Z (1985). The primary research about biomass of the *Aneurolepidium chinen* and *Stipa grandis* grassland community. In: Inner Mongolia Grassland Ecosystem Research Station, Chinese Academy of Science, eds. Research on Grassland Ecosystem. Beijing: Science Press, 12–22 (in Chinese)

Koerselman W, Meuleman A F M (1996). The vegetation N: P ratio: A new tool to detect the nature of nutrient limitation. J Appl Ecol, 33(6): 1,441–1,450

Margaret G, Anne W (1999). Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. Ecol Eng, 12:39–55

Ni H W, Zhang X, Jia L (1998). The aboveground biomass dynamics of *Deyeuxia angustifolia* population in typical meadow on Sanjiang Plain. Bull Bot Res, 18(3): 327–335 (in Chinese)

Nichiporovich A A (1959). Problem of Photosynthesis. USSR, Moscow: Publishing House of USSR Academy of Sciences

Romero J A, Brix H, Comin F A (1999). Interactive effects of N and P on growth, nutrient allocation and NH_4 uptake kinetics by *Phragmites australis*. Aquat Bot, 64(3/4): 369–380

Sun X L, Liu J S, Zhu Y R (2000). Nitrogen dynamics in different organs of *Calamagrostis angustifolia* and *Carex lasiocarpa* in Sanjiang Plain. Chin J Appl Ecol, 11(6): 893–897 (in Chinese)

Wang Q J, Wang W Y, Deng Z F (1998). The dynamics of biomass and the allocation of energy in alpine *Kobresia* meadow communities, Haibei region of Qinghai Province. Acta Phytoecol Sin, 22(3): 222–230 (in Chinese)

William J M, James G G J (1993). Wetland. New York: Van Nostrand Reinhold, 3–24

Woodmansee R G, Duncan D A (1980). Nitrogen and phosphorus dynamics and budgets in annual grasslands. Ecology, 6(4): 893–904

Xie Y H, Wen M Z, Yu D (2004). Growth and resource allocation of water hyacinth as affected by gradually increasing nutrient concentrations. Aquat Bot, 79: 257–266

Yang Y X, Wang S Y, He T R (2001). Distribution characteristics and seasonal dynamics of phosphorus and potassium in wetland ecosystem in the Sanjiang Plain. Chin J Appl Ecol, 12(4): 522–526 (in Chinese)

Yu W T, Yu Y Q (2001). Advances in the research of underground biomass. Chin J Appl Ecol, 12(6): 927–932 (in Chinese)

Zhang J E, Xu Q (1997). Perspective to the top points in the study of modern ecology. Adv Earth Sci, 16(3): 29–37 (in Chinese)

Zhu Q H, Qu X R, Li X Z (2000). Nutrient cycling in the reed field. Chin J Ecol, 19(6): 21–23 (in Chinese)

Zhu Z C, Jia D L (1996). A preliminary studies on the biomass of *Calamagrostis pseudqragmites* community. Acta Ecol Sin, 16(1): 40–49 (in Chinese)