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Nutrient resorption efficiency of three tree species in Beijing plain afforestation and its C:N:P stoichiometry

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Abstract Elucidating variability in nutrient resorption and carbon (C), nitrogen (N) and phosphorus (P) stoichiometry is important for holistically understanding plant approaches to nutrient adaption. However, the patterns of these phenomena in afforested regions of the Beijing Plain have been ignored. Herein, we assessed patterns of leaf and litter C, N, and P stoichiometry and nutrient resorption in *Robinia pseudoacacia* L., *Ailanthus altissima* (Mill.) Swingle, and *Salix matsudana* Koidz. forests in afforested areas in Beijing, China. We found that the plantation growth of *R. pseudoacacia* and *S. matsudana* was mainly limited by P nutrients. Both the N and P in the fresh leaves of *R. pseudoacacia* were significantly higher than those in the fresh leaves of *S. matsudana* and *A. altissima*, indicating that the N resorption efficiency (NRE) of *R. pseudoacacia* was higher. However, the P resorption efficiency (PRE) was significantly correlated with the leaf P nutrients in the *R. pseudoacacia* and *A. altissima* forests. Except for the significant correlation between the N content of fresh leaves and the AN content in soil, there were no significant correlations between the leaf C, N and P contents and the contents of these nutrients in the soil. These results suggested that of the factors studied, leaf P stoichiometry and PRE were more responsive indicators of the afforestation area on the Beijing Plain. Together, our data indicated that P deficiency is an important factor for the forests on the Beijing Plain and that the ability of afforested areas to adapt to barren land through nutrient resorption is gradually weakened and the N and P nutrient preservation ability is reduced over time. We thus clarified the nutrient resorption and leaf P and N patterns for the three forests studied. The findings have important implications for the application of P fertilizer, which must be conducted in a timely fashion to ensure that nutrient addition meets the nutritional needs of the plants.

Keywords: Nutrient resorption, leaf, litter, stoichiometry, Beijing plain afforestation

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Introduction

Afforestation plays an important role in wind prevention, sand fixation, and cropland protection (Paul et al. 2002). Since the five years, afforestation established since 2012, account for up to 78000 ha of total plain afforestation area in Beijing (Liu et al. 2015). *Robinia pseudoacacia*, *Ailanthus altissima*, and *Salix matsudana* are the most important tree species in plain afforestation, and account for up to 50% of the total plain area in Beijing. However, *R. pseudoacacia*, *A. altissima*, and *S. matsudana* stands (i.e., those planted in 2012) have undergone slow degradation due to abiotic factors, such as snow, human activity, and desertification, as well as biotic factors, such as issues caused by being planted in pure stands and problems with regeneration (Wang et al. 2017). To date, the mechanism has not yet been revealed.

Leaf stoichiometry can be employed to effectively assess plant nutrient limitations in the growth and development of forests (Koerselman & Meuleman 1996, Yan et al. 2017), and nutrient resorption represents an essential mechanism with profound influences on many processes, including plant growth, decomposition, and resource use efficiency, and plays a key role in the function and dynamics of ecosystems (Güsewell 2004). Particularly in nutrient-poor forest environments, leaf nutrient resorption is crucial for productive growth and element cycling (Cleveland et al. 2013). Therefore, both leaf stoichiometry and nutrient resorption may yield new insights into plant nutrient cycling, which may help to understand on the strategy of plant nutrient adaption.

Nutrient stoichiometry and resorption typically vary among tree species within forests due to nutrient uptake and utilization strategies and harsh environmental conditions (Amazonas et al. 2011). How tree nutrient stoichiometry and resorption vary with different species has been the subject of numerous studies, with inconsistent results (Pugnaire & Chapin 1993, Elser et al. 2010, Zhao et al. 2018). For example, Zhang et al. (2014) found that some evergreen trees increase the efficiency of nutrient resorption and utilization by reducing the nitrogen content in the litter leaves, so as to adapt to the harsh environment in Qinghai Tibet Plateau, while Yan et al. (2015) found Herbaceous plants have high resorption ability to the main elements which restrict their growth in dry hot valley.

Plants that exhibit robust nutrient resorption activity are better able to utilize their own internal nutrient supplies without losing them via litter. However, as essential nutrients, including C, N and P, can also limit plant growth (Elser et al. 2003). The N resorption efficiency (NRE) and P resorption efficiency (PRE) are related to the nutrient demand of plant (Sun et al. 2016), and NRE and PRE usually affects the normal uptake of mineral elements in plants and further causes the plants abnormal growth and development (Du et al. 2017). Effective resorption of the mineral elements before leaves are shed provides an important mechanism for conservation. Moreover, most researches have inconsistencies may result from element-specific (Wang et al. 2015), or species-specific responses (Gyenge & Fernández 2014). Therefore, it is an important aspect to measure the relationship between stoichiometry and nutrient resorption to reveal the possible survival mechanism due to nutrient limitation for a given species.

Apart from tree species, one of conclusions is that organisms must change their C:N:P stoichiometry as a function of their growth rate (Sterner & Elser 2002, Tessier & Raynal 2003). Plant growth does not only rely on a single nutrient's availability, but on the balance between multiple nutrients (Vitousek 2003). This is the case, for instance, C:N and C:P of plant leaves largely reflect the competitiveness and adaptability of plants to poor environment, and N:P can be used as the main basis for evaluating the nutrient limitation of plants (Ågren 2008). Thus, ecological stoichiometry has provided an integrative solution to measure changes in C, N and P within a plant at a given time (Kobe et al. 2005). In Beijing plain, nutrient deficiency and imbalance are serious problems (Cui et al. 2015), and it is important to understand the effects of leaf nutrient stoichiometry and nutrient resorption with different afforestation forests.

In this study, we examined leaf C, N, and P stoichiometric patterns and nutrient resorption in *R. pseudoacacia*, *A. altissima*, and *S. matsudana* forests in the Beijing Plain afforestation area. In addition, we assessed how tree species and leaf and litter stoichiometry influence C, N and P stoichiometry and nutrient resorption with the goal of assessing the following: (1) the leaf and litter C, N, P stoichiometry patterns and N and P resorption efficiency in *R. pseudoacacia*, *A. altissima*, and *S. matsudana* forests in the Beijing Plain afforestation ecosystems; (2) nutrient resorption, with different forests, also significantly impact on C, N, and P stoichiometry; (3) the elements that serve as relatively limiting nutrients in these forests. Together, these analyses can provide details regarding key nutrient factors critical for the afforestation of plains, and the results should provide novel insights that allow us to better understand afforested areas in light of nutrient limitations, and also provide a theoretical basis for forest management on the Beijing Plain.

Material and methods

Study site

R. pseudoacacia, *A. altissima*, and *S. matsudana* are three broad-leaved of the family Fabaceae Lindl., Simaroubaceae DC. and Salicaceae Mirb., respectively. Following its discovery as a living species, the species has been planted in numerous locations throughout the Beijing, with a wide range of mean annual temperature. Since 2012, the species have been planted along eastern and northern of Beijing for controlling erosion and reducing wind damage under "Beijing plain afforestation program" (Wang et al. 2017). *R. pseudoacacia*, *A. altissima*, and *S. matsudana* becomes the main species of shelterbelts in Beijing.

The study was conducted in Beijing (39°30′13.99″ N, 116°15′26.54″ E) (Figure 1). It features 30-45 m above sea level. The annual average temperature is 11.5 °C, the precipitation is 568.9 mm, the rainfall is mainly concentrated in July-September, and humidity of 63-68%. Before the implementation of the plain forest construction, the study area was the sand wasteland, the lotus root land of potholes and the land for conversion of farmland to forest (Zheng et al. 2018). Its own land force is relatively weak compared with the natural forest, mainly distributed in light loamy brown tide soil and sandy loam soil, and the pH value is 8.8-9.1.

Figure 1 Location of the forest plots studied in Beijing of China

Experiment design and sample collection

The study site was the pioneer area to plant the *R. pseudoacacia*, *A. altissima*, and *S. matsudana* in plain Beijing. In late August 2019, *R. pseudoacacia*, *A. altissima*, and *S. matsudana* forests were investigated in Daxing forest farm. These forests were with similar site conditions and less human activity since afforested in 2012. Based on a comprehensive review of the Beijing plain plantations, we selected the study site that reflected the mean elevation, aspect, and soil conditions within the plantations. All sites had similar soils, climate, land-use history. Each tree species had three replicates with similar terrain characteristics. Three replicates of plot, with the site conditions, such as landform, altitude, soil type and slope, were nearly identical, 20×20 m, were established in each tree species. The diameter at breast height (DBH) was measured for all trees in each plot (Table 1). Based on DBH, five standard trees were randomly selected in each plot, which were selected for collecting leaves. Fully expanded leaves from the upper and outer part of tree crowns were sampled, and thoroughly mixed to homogenize a sample. Three 1×1 m litter traps (made of nylon mesh) per plot were fixed 1.0 m above the ground. Leaf litter was collected in late November 2019. The litter in the samples was harvested, weighed after being mixed, and taken back to the laboratory for drying at 80 °C in an oven. The leaves and litter of each forest were collected using a plant crusher and the impurities were removed, the purity of litter was guaranteed. Five soil cores (2.5 cm in diameter) per plot were randomly collected from 0 to 20 cm depth following removal of understory plants and surface litter, and thoroughly mixed to homogenize a sample. The mixed soil sample of topsoil was collected from that of litter sample using the soil drilling method and taken back to the laboratory.

Table 1 Basic status of sampling sites and trees

Forest type	Elevation (m)	Slope (°)	Age (a)	Mean DBH (cm)	Mean tree height (m)	Density (tree/hm^2)	Coverage (%)
R. pseudoacacia	40	6	7	13.62 ±1.03	5.8±0.54	678±25	0.78
A. altissima	41	6	7	13.3±0.95	6.9±0.76	589±88	0.85
S. matsudana	45	6	7	17.1±1.21	11.1±1.01	633±54	0.80

Notes: Values are presented as the mean ± standard deviation (SD). Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected (n = 15).

Chemical measurements

The C and N concentration were determined for each sample using an autoanalyzer (Kjeltec 2300 Analyzer Unit, Foss, Sweden). Leaf and litter organic carbon and soil organic carbon (SOC) was determined with wet oxidation by sulfuric acid and potassium dichromate and back titration with ferrous sulfate. The total N (TN) was measured using the semi-micro Kjeldahl method with a Kjeldahl Auto-analyzer (KDN-102C, Shanghai, China), total P (TP) concentration was measured using the HNO_3 digest-Mo-Sb antispectrophotography method using a spectrophotometer (UV-2102 PCS, Shanghai, China). Available P concentration (AP) was determined with molybdate blue colorimeter after extraction with 0.5 M sodium bicarbonate, alkali-hydrolyzable nitroge was measured using Alkaline hydrolysis diffusion method. The ecological stoichiometric ratios of C, N and P were calculated as C vs. total N (C:N), C vs. total P (C:P) and total N vs. total P (N:P).

Data analysis

Nutrient resorption efficiency (NuRE) was defined as the proportional withdrawal of a nutrient during senescence and was calculated by equation:

$$NuRE = \left(1 - \frac{X_{litter}}{X_{leaf}} \times MLCF\right) \times 100\%,$$ where

NuRE is N or P resorption efficiency, X_{leaf} and X_{litter} represent N or P concentration (mass based) in leaf and litter respectively, and where MLCF is mass loss correction factor and about 0.784 for deciduous broadleaved species (Vergutz et al. 2012). Each tree species represents an average value across three replicate plots (n = 15), five soil samples per plot were randomly collected, i.e., three plots repeats × five soil samples. Values are presented as the mean ± standard deviation (SD). One-way ANOVA was used to test the differences of leaf C, N, P stoichiometry and nutrient resorption among three forests, and a least significant difference post hoc test was used to test for significant differences at the 0.05 and 0.01 levels, p-values < 0.05 and <0.01 were considered statistically significant, respectively. Pearson correlation analyses were performed to test the relationships between leaf and litter stoichiometry and nutrient resorption and soil nutrients of forests. Regression analyses were used to examine the relationships between tree stoichiometry, nutrient resorption and leaf N and P stoichiometry. All analyses were performed using by SigmaPlot 10.0 (Systat Software, Inc., Richmod, CA, USA). Statistically significant differences were recognized at $p < 0.05$.

Results

Variations in leaf and litter C, N, P contents and stoichiometry of three forests

Leaf C, N, P contents differed significantly among three plantations (Table 2). The highest fresh leaf N and P contents values were obtained in *R. pseudoacacia*, respectively 26.32 g·kg^{-1} and 1.56 g·kg^{-1}, while the highest fresh leaf C contents values (457.55 g·kg^{-1}) were obtained in *S. matsudana*. C, N, P stoichiometry of fresh leaves and litters showed significant differences among three plantations (Table 3). The fresh leaf C:N and C:P ratios were higher in the *S. matsudana* plantation than in the other plantations. The N:P ratio of *R. pseudoacacia* was significantly elevated relative to that in the fresh leaves in the three forests. In contrast, the litter C:N, C:P, and N:P ratios were highest for *S. matsudana*, with values of 25.41, 868.7 and 16.64, respectively.

Table 2 C, N, P contents of fresh leaf and litter in three tree species

Type	Tree species	C content (g·kg^{-1})	N content (g·kg^{-1})	P content (g·kg^{-1})
Fresh leaf	*R. pseudoacacia*	378.12±18.21b	26.32±3.44a	1.56±0.04a
	A. altissima	342.27±9.34c	16.64±5.38b	1.02±0.09a
	S. matsudana	401.81±21.55a	15.26±7.77b	0.98±0.05b
Litter	*R. pseudoacacia*	337.81±19.33c	17.34±1.89b	1.41±0.04a
	A. altissima	411.17±12.17b	20.92±1.31a	1.01±0.01b
	S. matsudana	457.55±9.74a	15.01±2.07c	0.42±0.03c

Notes: Different lowercase letters in the same column indicate significant difference at $p < 0.05$ level. Values are presented as the mean ± standard deviation (SD). Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected (n = 15).

Table 3 C, N, P stoichiometry of fresh leaf and litter in three tree species

Type	Tree species	C: N	C:P	N:P
Fresh leaf	*R. pseudoacacia*	14.53±1.87c	512.33±31.44c	25.18±1.88a
	A. altissima	18.36±2.34b	640.28±28.17b	11.94±1.32c
	S. matsudana	23.22±3.13a	651.22±44.23a	18.76±2.11b
Litter	*R. pseudoacacia*	19.82±1.96b	508.19±47.29c	13.54±2.36b
	A. altissima	20.8±4.44b	536.79±27.24b	14.35±1.28b
	S. matsudana	25.41±3.12a	868.7±26.45a	16.64±3.18a

Note Different lowercase letters in the same column indicate significant difference at $p < 0.05$ level. Values are presented as the mean ± standard deviation (SD). Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected ($n = 15$).

Nutrient resorption efficiency

The mean NRE values of the three forests, which showed the N resorption activities of the three plantations, were ordered as follows: *R. pseudoacacia* > *S. matsudana* > *A. altissima* (Figure 2). The highest NRE, which ranged between 50.34% and 73.47%, occurred in the *R. pseudoacacia* plantation ($p < 0.05$). In contrast, the *S. matsudana* plantation had a PRE value ranged between 43.26% and 52.62%, which was much higher than that in *A. altissima*, and *R. pseudoacacia* plantations with corresponding PRE value of 22.34% and 18.70%, respectively ($p < 0.05$).

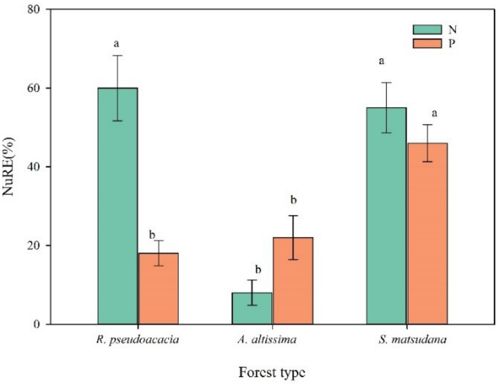

Figure 2 N, P resorption efficiency in three forests. Different lowercase letters indicate significant differences among different forests ($p < 0.05$)

Effects of nutrient resorption efficiency of fresh leaf and litter and stoichiometry in three forests

Nutrient resorption efficiency of fresh leaf and litter were also related to C, N, and P stoichiometry in three forests (Table 4). The NRE was positively significantly associated with litter C:N and significantly negatively correlated with litter N:P in the *R. pseudoacacia* forest ($p < 0.01$).There was a negative correlation between NRE and N:P in litter of *A. altissima*, and negative correlations were observed between PRE and C:N, and C:P in fresh leaf of *A. altissima* ($p < 0.05$).In addition, NRE positively correlated with C:N, while negatively correlated with N:P in litter of *S. matsudana* ($p < 0.05$). In contrast, PRE was positively associated with C:N in fresh leaf of *S. matsudana* ($p < 0.05$). No significant correlations were observed in other cases. The leaf N contents of the three plantations displayed no significant relationship with the NRE (Figure 3). By contrast, PRE was correlated with leaf P nutrient in *R. pseudoacacia* and *S. matsudana* plantations, except *A. altissima* plantations (Figure 4). The average AN in *R. pseudoacacia* forest was significantly higher than that in *A. altissima* and *S. matsudana* forest (Table 5). The TN in the fresh leaves and AN in the soil were significantly positively correlated (Table 6, $p < 0.05$), while the contents of C, N and P in the litters showed nonsignificant differences with the soil nutrient contents.

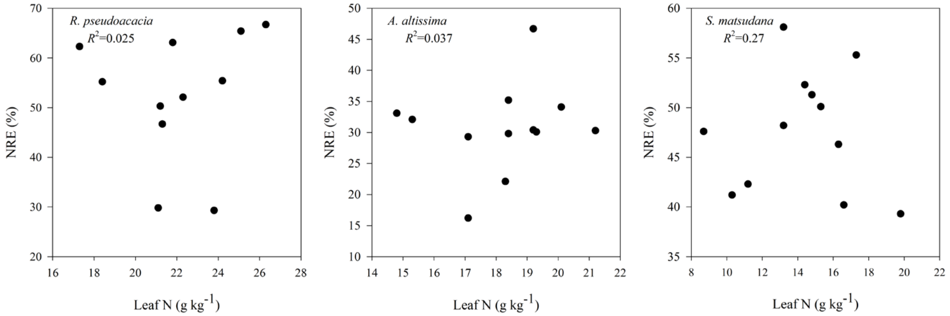

Figure 3 Relationships between N resorption efficiency (NRE) and leaf stoichiometry

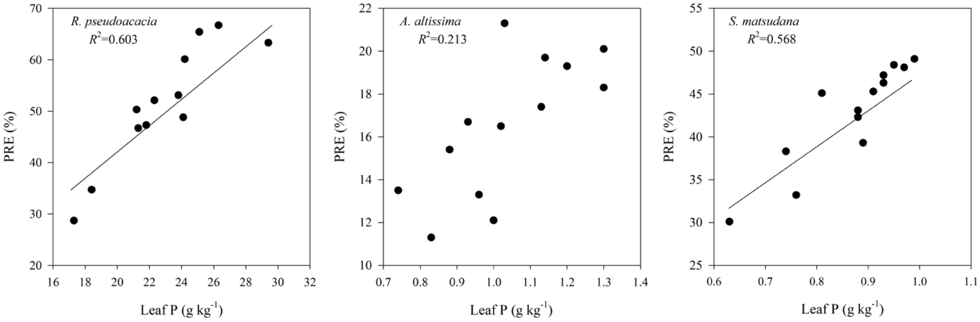

Figure 4 Relationships between P resorption efficiency (PRE) and leaf stoichiometry

Table 4 Correlations between N, P resorption efficiency (RE) of fresh leaf and litter and C, N, P stoichiometric characteristics in three tree species

		Fresh leaf			Litter		
Tree species	RE	C:N	C:P	N:P	C:N	C:P	N:P
R. pseudoacacia	NRE	-0.255	-0.023	-0.093	0.877**	0.307	-0.863**
	PRE	0.316	0.116	-0.352	-0.443	-0.06	0.443
A. altissima	NRE	-0.612	-0.323	0.093	0.141	-0.153	-0.618*
	PRE	-0.667*	-0.668*	-0.523	-0.04	-0,302	-0.323
S. matsudana	NRE	-0.135	-0.122	0.634	0.732*	0.052	-0.693*
	PRE	0.501*	0.374	0.102	-0.087	0.371	0.061

Notes: *indicates $P < 0.05$; ** indicates $p < 0.01$. Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected (n = 15).

Table 5 Soil properties of three different forests sample plots

Plantation type	SOC ($g\cdot kg^{-1}$)	TN ($g\cdot kg^{-1}$)	TP ($g\cdot kg^{-1}$)	AN ($mg\cdot kg^{-1}$)	AP ($mg\cdot kg^{-1}$)
R. pseudoacacia	37.57 ± 10.03a	1.72 ± 0.58a	1.09 ± 0.05a	214.93 ± 31.68a	47.51 ± 17.73a
A. altissima	23.14 ± 7.15a	1.53 ± 0.52a	1.64 ± 0.02a	113.87 ± 40.01b	29.41 ± 20.83a
S. matsudana	22.92 ± 4.06a	1.95 ± 0.52a	1.07 ± 0.03a	101 ± 32.18b	24.11 ± 14.53a

Notes: SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; AN, alkali-hydrolyzable nitrogen; AP, available phosphorus. Different lowercase letters in the same column indicate significant difference at $P < 0.05$ level. Values are presented as the mean ± standard deviation (SD). Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected ($n = 15$).

Table 6 Pearson's correlation coefficients between nutrient contents in leaves, litters and soil properties (SOC, TN, TP, AN, AP and pH)

Type	Soil properties	SOC	TN	TP	AN	AP	pH
Fresh leaf	SOC	0.131	0.336	-0.238	-0.092	0.231	0.036
	TN	-0.094	-0.242	-0.114	0.621*	0.366	0.057
	TP	-0.035	-0.219	-0.069	0.245	0.279	0.277
Litter	SOC	0.211	-0.057	-0.213	-0.136	-0.037	0.013
	TN	-0.367	0.331	0.083	0.075	-0.493	0.213
	TP	-0.154	-0.146	0.037	0.130	0.348	0.352

Notes: *indicates $p < 0.05$. Notes: SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; AN, alkali-hydrolyzable nitrogen; AP, available phosphorus. Each tree species represents an average value across three replicate plots, five soil samples per plot were randomly collected ($n = 15$).

Discussion

Plants and soil are closely linked, and their interactions have important implications for in a plant-soil system due to variations in soil nutrient availability and plant nutrient status. In our study, no significant correlation between the contents of C, N and P in the fresh leaves and litter of three trees was detected, with the exception of the N in the fresh leaves and the in the soil; this was in contrast to some previous studies that found that plant species, local climate and soil nutrients may affect the N and P contents in plant leaves (Elser et al. 2010, Vergutz et al. 2012). In addition, because the soil nutrients showed nonsignificant trends among the different forest types and the climate, elevation and slope of the sample plots were basically the same, the total soil nutrients in the study area were not the primary reason for the differences in nutrient contents in the different plantations. The availability of nutrients, especially AN, was the main factor controlling the N content in the fresh leaves. This suggested that higher supply of N from leaf caused the accumulation of N in soil (Reich & Oleksyn 2004). Therefore, the supply of N becomes increasingly important for the sustainability of plantations over time. The leaf N and P of *R. pseudoacacia* were significantly higher than *A. altissima* and *S. matsudana*, because *R. pseudoacacia* was a *Leguminosae* plants have strong ability of nitrogen fixation, it could improve the soil N availability and nutrient cycling (Houlton et al. 2008). This was consistent with Zhu et al. (2010), who reported that leguminous plants have higher leaf nitrogen content. We thus posit that replacing trees used for afforestation with species capable of N fixation or that are less competitive can benefit overall soil fertility and productivity.

Leaf nutrient resorption is a vital constituent in plant-soil system to improve nutrient cycling especially in nutrient-poor environment (Vergutz et al. 2012). Nutrient resorption efficiency differs by species, and the resorption characteristics of the same species in different habitats are also different. The NRE was higher in the *R. pseudoacacia* forest than in the other forests, whereas the PRE was higher in the *S. matsudana* forest. This is because of the biological nitrogen fixation capacity of leguminous species and because the overall N cycle of these species differs greatly from that of non-nitrogen-fixing plants (Boddey et al. 2000), resulting in a significant difference between the *R. pseudoacacia* forest and the other two forests. According to the study on nutrient resorption rate of various terrestrial plants by Vergutz et al. (2012) on a global scale, the results showed that N and P had high nutrient resorption rates (respectively 62.1%, 64.9%). However, in our study, the NRE and PRE of the three forests in Beijing plain were lower than the above results. Some studies have suggested that nutrient transfer and resorption may only be an inherent feature of the species, and genetic differences may be the main factor determining nutrient resorption (Killingbeck 1996, Luyssaert et al. 2005). Moreover, due to the different habitats in the study area, the plant nutrient resorption rate showed specificity (Reed et al. 2012).

Previous studies have found that the C:N and N:P ratios in litter are often negatively correlated with the litter decomposition rate (Vitousek et al. 1994). The results of this study showed that the C:N and N:P ratios of *R. pseudoacacia* were lower than those of S. *matsudana* and *A. altissima*, indicating that the decomposition rate of *R. pseudoacacia* was the fastest among the three forests. In addition, the higher the C:N and C:P of fresh leaves is, the stronger the competition ability and adaptability to poor environments; moreover, the content of N in fresh *R. pseudoacacia* leaves was much higher than that in the other two species, and the PRE was the lowest. This suggested that mature *R. pseudoacacia* can increase the N content and reduce the C:N and N:P ratios in their leaves through nitrogen fixation. This ability helped to accelerate the decomposition rate and reduce the resorption rate of P, promoting the recycling efficiency of P in the soil.

In this study, the NRE of *R. pseudoacacia* was significantly positively correlated with the C:N ration and negatively correlated with the N:P ratio, which was consistent with the results showing higher N and P utilization efficiency by *R. pseudoacacia*. For *A. altissima*, there was a significant negative correlation between the NRE and fresh leaf N:P ratio ($p < 0.05$) and the PRE was negatively correlated with the C:N and C:P ratios of fresh leaves. The results showed that the effect of PRE was greater than that of NRE on the stoichiometric characteristics, which was consistent with the conclusions of Vitousek et al. (1994) that the growth of *A. altissima* was limited by P. The P content was not completely absorbed in the *R. pseudoacacia* or *A. altissima* forests, indicating that the ability of mature *R. pseudoacacia* and *A. altissima* on the Beijing Plain to adapt to barren sites through nutrient resorption was relatively weak and that the ability for N and P nutrient conservation and self-transfer was low. This phenomenon suggests that when plant growth is restricted by certain elements due to environmental nutrient imbalance, plants tend to have a higher resorption efficiency of those restrictive elements, thus forming a feedback loop with the environment. This finding supported the “relative resorption hypothesis” that plants would resorb proportionally more N or P when plants are growing under N- or P-limited conditions (Güsewell 2005). Therefore, the relative changes in NRE and PRE probably reflect the variation in nutrient retrieval strategies among species in response to environments (Rejmánková 2005). Based on our data, PRE showed a curve correlation leaf P in *R. pseudoacacia* and *A. altissima* forests, which suggested that leaf was more sensitive to changes in PRE (Schreeg et al. 2014), thus, plants that grew in relatively infertile soils could translocate more P nutrient from leaves to storage before litter fall (Hayes et al. 2014), resulting in the change of resorption efficiency. When the nutrients are insufficient and cannot be supplemented, the nutrient supply of the system will become the main factor restricting the growth of plants sooner or later. The nutrient resorption efficiency of plants growing in this habitat is low, which indicates that the preservation capacity of N and P nutrients of plants is reduced, plants showed a declining trend in nutrient conservation. Our results revealed that P deficiency was the leading factors, in terms of nutrients, adaptive P addition strategies may need to be considered to improve P-limitation status. In addition, for the tree species selection, it is a feasible method that selecting proper low P tolerance breedings in establishment of plain afforestation in future.

Conclusions

R. pseudoacacia, *S. matsudana*, and *A. altissima* are common tree species in Beijing plain afforestation area. Identifying their mechanisms for adapting to the plain habitat can provide a theoretical basis for selecting suitable plants for this region. The low N:P ratios of these species are indicative of the fact that the growth of *R. pseudoacacia* and *S. matsudana* was mainly limited by P. The N and P in the fresh leaves of *R. pseudoacacia* were significantly higher than those in the fresh leaves of *S. matsudana* and *A. altissima*, indicating that the NRE of *R. pseudoacacia* was higher. However, the PRE was correlated with the leaf P nutrients in the *R. pseudoacacia* and *A. altissima* forests. These findings demonstrated that leaf P stoichiometry and PRE were more responsive indicators for plain afforestation area of Beijing. We thus detected patterns of leaf nutrient stoichiometry and resorption among the three studied forests, which have important implications for P fertilizer should be added in a timely way to meet the nutritional needs. Future research should address the long-term effects of different forest management practices on tree C, N, and P stoichiometry and to gain a better understanding of the temporal dynamics of NuRE in intensively managed plantations. Furthermore, appropriate forest management strategies should be considered to improve P-limitation status of the Beijing plain plantation ecosystems.

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