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ECOLOGICAL STOICHIOMETRIC CHARACTERISTICS OF CARBON, NITROGEN AND PHOSPHORUS OF DIFFERENT PLANT FUNCTIONAL GROUPS IN NORTHWESTERN GUIZHOU PROVINCE, CHINA

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Abstract

The carbon (C), nitrogen (N) and phosphorus (P) ecological stoichiometric characteristics of plants from northwestern Guizhou Province, China was explored, to better understand their adaptation strategy in cold and drought-affected habitats and to improve the management of sustainable forestry. Leaves of four plant types (evergreen arbors, deciduous arbors, evergreen shrubs and deciduous shrubs), as well as the surrounding litter and soil, were collected and the concentrations of C, N and P were determined. Our study showed: (1) lower nutrient concentrations in plant leaves and soils in this area; and (2) that the nutrient concentrations may be affected by plant species, which is significant in deciduous arbors. The C:N, C:P and N:P ratios were greatest in the litter, smaller in leaves and lowest in soil. Large N:P ratios have been found in the litter of evergreen and deciduous arbor species. We found no significant relationship between nutrient concentrations in soil and plant leaves. N may be an important factor for plant growth in this area. Of the four plant types selected, deciduous shrubs were found to have a great ability to absorb nutrients from their habitats, while evergreen arbors adapted to their habitats by strengthening their defense capability. Evergreen and deciduous shrubs have a beneficial ecological function by conserving water and soil. Our study has provided a theoretic basis for the construction and management of plantation in northwestern Guizhou Province, China.

Key words: Plant functional group; Ecological stoichiometry; Soil; Leaves; Litter.

Introduction

Ecological stoichiometry has been applied to study the relationships between the energy and chemical elements in ecological processes using the basic theories of biology, chemistry and physics. It has provided a new way to study the relationships during ecosystem processes among some significant elements—such as carbon (C), nitrogen (N) and phosphorus (P)—by combining variable biotic scales, groups and different areas of ecology into a community ecology (Elser *et al.*, 1996; Michaels, 2003; He & Han, 2010). C is considered to be a plant structural element, and N and P are functional limiting elements. As the most important elements in soils, their concentrations can be used to represent the level of soil fertility (Kevin, 2019; Güsewell, 2004). They are also the key elements for plant growth and have significance in adaptation to the environmental stress (Du *et al.*, 2020). The stoichiometric ratio of elements reflects the efficiency with which these nutrients are used during their cycling within plants, litter and soil. The ratio also has significance in in allowing an assessment of fertility in ecological system (John *et al.*, 2020; Wang *et al.*, 2014). It is therefore important and meaningful to study the ecological stoichiometric characteristics of plant, litter and soil from various functional groups in forest ecosystems. The application of nutrient ratios to assess nutrients in leaf-litter-soil continuum can reveal the relationships between elements, as well as illustrating the mechanism of sustainable resource utilization during the ecology process.

A plant functional group is a combination of plants with specific functional characteristics. It can be used as a basic unit to study the dynamic change of plants in the environment (Mackie *et al.*, 2019; Elumeeva *et al.*, 2018). Plants from the same group have similar responses to environmental and ecosystem changes (Walker, 1992; Noble & Gitay, 1996), and these responses may be seen in different generations. Plant species (Yan *et al.*, 2015a) and communities (Fan *et al.*, 2015; Yan *et al.*, 2015b) have been used in ecological stoichiometric studies to better understand nutrient cycling and the stabilized mechanism of a system. There are, however, several advantages in running environmental studies by using plant functional groups. For example, this will decrease the complexity of a forest ecosystem study, and studying the composition, structure and dynamics of a community will be easier. Plant functional groups reflect the response mechanism to a turbulence and illustrate the influence mechanism of species during ecosystem process.

Previous studies have shown that there is a difference in limitation of nutrients among plant species, illustrating a dynamic relationship between concentrations of various nutrients and their ratios during different growing stages (Fan *et al.*, 2015). Fan *et al*., (2015) proved the dynamic relationship between the concentrations, balance and production of elements during the growth stage provided a theoretical basis for forest management. Atmospheric N concentrations have been increasing rapidly as their sources and distribution have expanded globally (Galloway & Cowling, 2002; Galloway *et al.*, 2003). A new relationship has developed by the addition of this nutrient into the system (Ai *et al.*, 2017), which could better in applying the fertilization. Stoichiometric characteristics of plant leaves vary greatly with plant species, functional groups and species (Sterner & Elser, 2002; Ågren, 2004; Reich & Oleksyn, 2004). Because few studies have been done on the stoichiometric characteristics of plant functional groups, more work is needed to better understand plant growth in diverse rocky deserts, and on the limiting elements affecting the growth of different plant functional groups.

The stoichiometric characteristics of C, N and P from a karst plateau forest ecosystem in northwestern Guizhou was explored. This will improve understanding of nutrient limitation in the forest and affect its future management. We chose plants from different functional groups and measured their C, N and P content; applied ecological stoichiometrics to determine the C, N and P characteristics; and then illustrated the nutrient variations. This revealed the cycling mechanism of nutrients in the karst plateau mountain forest ecosystem, and contributes to optimizing the plant community structure and sustainable forest management.

Materials and Methods

Sampling area: The study area is located in a tributary area (27°11'36″–27°16'51″ N, 105°02'01″–105°08'09″ E) of the Liuchong River Basin in western Bijie, Guizhou Province, China. This area lies in a karst plateau mountain environment, with an average annual rainfall of 863 mm and an annual average temperature of ~14°C. The landforms are diverse and the terrain is fragmented. Cultivated land is mostly distributed on slopes, terraces and in mountain valleys, often forming terrace fields around mountains and dam fields in valleys. There are aboveground and underground rivers, funnels, blind valleys, sinkholes, skylights and karst depressions. Regional vegetation mainly comprises coniferous and broad-leaved mixed forest. The major soil type is yellow soil, with mountain yellow brown soil and calcareous soil being found in some areas (Guan *et al.*, 2016).

Experiment design: Plants with a good ability to recover from hard living conditions, and experiencing limited human interference, were investigated in July 2016. Their specific names, height, diameter, ground diameter, crown breadth, etc., and growth and morphologic indexes, were recorded. This allowed them to be grouped into evergreen arbors, deciduous arbors, evergreen shrubs and deciduous shrubs on the basis of growth form (Table 1).

Rhododendron simsii and *Populus alba* are widely distributed in northwestern Guizhou. The climate in this area is cold and arid, so these plants adapt to the hydrothermal conditions by defoliation. *Pinus armandii* and *P. yunnanensis* are coniferous tree species; the latter is usually grown above 1 100 m and is also the dominant tree species in the high-elevation region. *Quercus fabri*, *Corylus heterophylla*, *Castanea mollissima* and *Q. variabilis* are broad-leaf shrubs which can suffer from arid habitats; they return nutrients by defoliation. *Pyracantha fortuneana*, *Coriaria sinica*, *Rhododendron simsii* and *Hypericum monogynum* are low growing and have a small crown breadth, but are shade tolerant and dominant species in the shrub layer.

Sample collection and C, N and P determination: Three sample plots with similar slope position and direction, gradient and altitude were selected for the same plant community. The size of each plot was 20 m × 20 m; five trees were selected according to the S-type route in each plot, which was far away from other tree species and relatively less affected. We used a multi-point mixing method to collect their leaves, surface litter and root zone soil. Well-growing, disease-free and mature leaves were collected before 11:00 a.m., mixed into nylon mesh bags and brought back to the laboratory. The samples were dried in a constant temperature drying oven at 65°C to constant mass, finely ground and mixed thoroughly for later use. The litter from the target tree species was randomly and uniformly collected within a range of 0–150 cm from the base of the tree trunk, and pretreated in the same manner as the leaves. When collecting the soil in the root zone, we collected soil 20–30 cm from the base of the tree trunk and 100–150 cm away from other varieties of trees. Soil was taken from depths of 0–20 cm from multiple points, mixed well and divided into four parts, we took approximately 1 kg back to the laboratory. A total of 500 g every plant leaves was taken from mutual plants experiencing good growing conditions. Only pest-free, fully extended leaves were collected from four directions of a tree. Fresh litter and soil were also collected into clean sample bags. Soil samples were air dried in the laboratory, and roots, gravel and animal residues were then removed. Plant leaves, litter and soil were digested by using the potassium dichromate external heating method (NY/T 1121.6-2006), and C concentrations were determined. To determine N concentrations in leaves, litter and soils, samples were digested using the $HClO_4$-H_2SO_4 digestion method. Total P was measured by Mo-Sb colorimetric UV spectrophotometry after samples were digested by $HClO_4$-H_2SO_4.

Table 1. Basic plant parameters.

Plant species	Longitude and latitude	Altitude /m	Slope/	Direction	Slope position	Soil type	Tree height /m	Functional group
Pinus yunnanensis	27˚14′31.06″,105˚04′55.48″	1832	28	Southwest	Middle	Yellow soil	16.0	Evergreen arbors
Pinus armandii	27˚14′31.06″,105˚04′55.48″	1832	28	Southwest	Middle	Yellow soil	13.8	Evergreen arbors
Quercus fabri	27˚14′31.06″,105˚04′55.48″	1832	28	Southwest	Middle	Yellow soil	3.0	Deciduous shrubs
Pyracantha fortuneana	27˚14′30.13″,105˚04′53.83″	1852	32	Southwest	Middle	Yellow soil	1.8	Evergreen shrubs
Coriaria sinica	27˚14′31.06″,105˚04′55.48″	1852	32	Southwest	Middle	Yellow soil	0.9	Evergreen shrubs
Quercus variabilis	27˚14′04.69″,105˚04′59.53″	1847	33	South	Middle	Yellow soil	2.2	Deciduous shrubs
Corylus heterophylla	27˚14′04.69″,105˚04′59.53″	1847	33	South	Middle	Yellow soil	1.7	Deciduous shrubs
Castanea mollissima	27º14′09.81″,105º04′56.73″	1800	50	Southwest	Middle	Lime soil	3.5	Deciduous shrubs
Rhododendron simsii	27º14′09.81″,105º04′56.73″	1800	50	Southwest	Middle	Lime soil	3.5	Evergreen shrubs
Rhododendron simsii	27º14′31.37″,105º05′06.94″	1850	33	Southwest	Upper	Yellow soil	16.3	Deciduous arbors
Hypericum monogynum	27º14′31.37″,105º05′06.94″	1850	33	Southwest	Upper	Yellow soil	1.0	Evergreen shrubs
Populus alba	27º14′11.50″,105º05′00.83″	1811	20	southeast	Middle	Yellow soil	15.2	Deciduous arbors

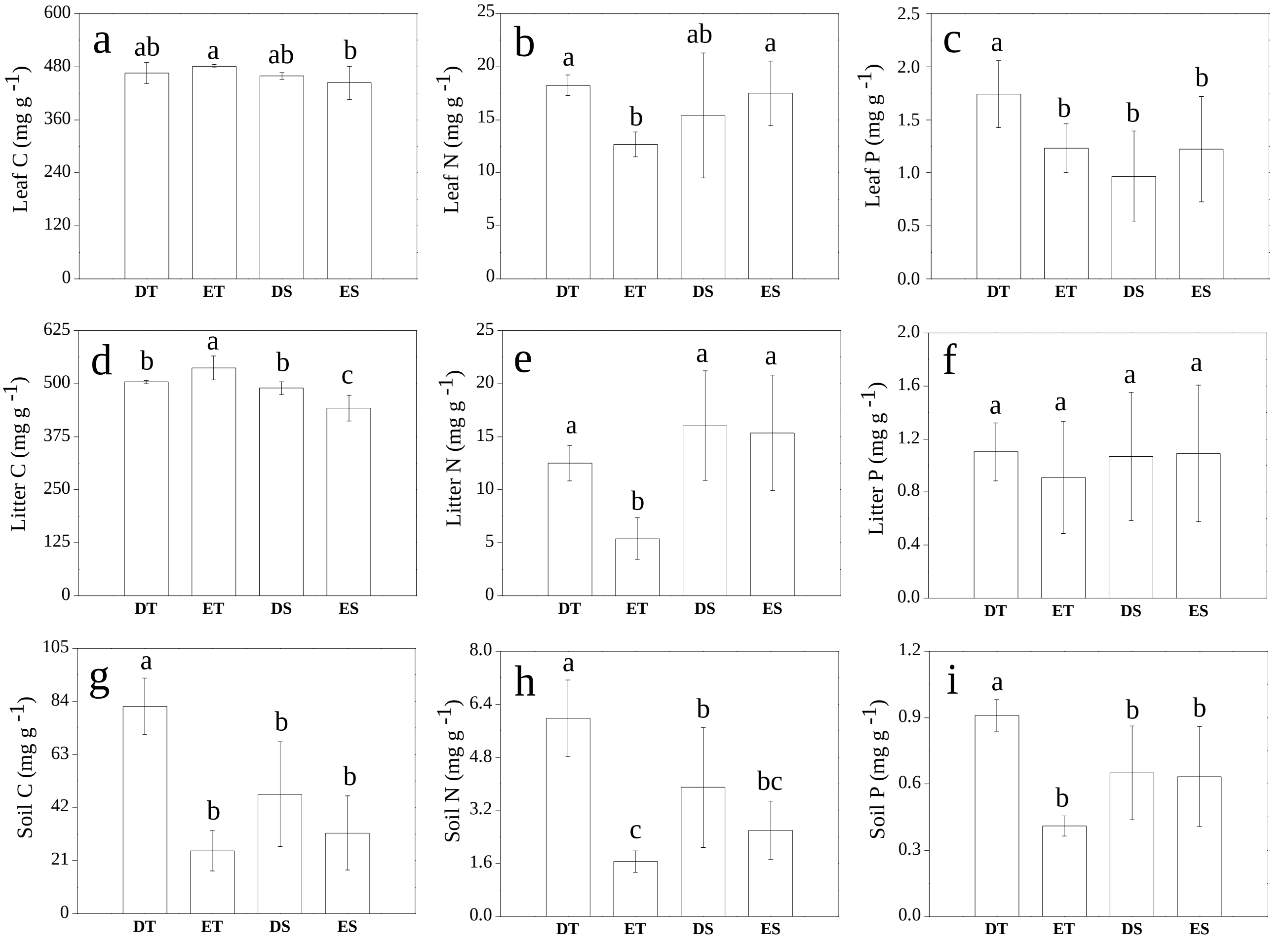

Fig. 1. C, N and P concentrations in different plant functional groups. DT, deciduous arbors; ET, evergreen arbors; DS, deciduous shrubs; ES, evergreen shrubs. Values are the mean ± standard deviation of four plant functional groups. Letters indicate significant differences among the groups at *p*<0.05.

Data processing: The C:N:P ratios in leaf, litter and soil were presented by mass ratios (He & Han, 2010). Microsoft Excel 2010 (Microsoft Corp, USA) was used for data treatment, and figures were plotted with Origin 8.6 (Microcal Corp, USA). SPSS 21.0 (Statistical Package for the Social Sciences-IBM Corporation, Armonk, New York, USA) was used for statistical analysis and normal distribution of samples was tested by the K–S test. All data should agree with normal distribution. Differences in C, N and P content of the plant leaf, litter and soil and their stoichiometric relationships were determined by one-way ANOVA, *p*<0.05.

Results

C, N and P concentrations in different plant functional groups: Significant differences between C, N and P concentrations were determined in different plant functional groups (Fig. 1): these were highest in leaves, followed by soil and litter. The concentrations of C in evergreen arbors were 481.33mg g^{-1}, greater than those of deciduous arbors (465.80 mg g^{-1}), deciduous shrubs (458.95 mg g^{-1}) and evergreen shrubs (443.64 mg g^{-1}). The concentrations of total N were higher in deciduous arbors (18.25 mg g^{-1}), followed by evergreen shrubs (17.49 mg g^{-1}), deciduous shrubs (15.41 mg g^{-1}) and evergreen arbors (12.68 mg g^{-1}). The concentrations of total P in deciduous arbors were 1.74 mg g^{-1}, greater than those of evergreen arbors (1.23 mg g^{-1}), evergreen shrubs (1.22 mg g^{-1}) and deciduous shrubs (0.97 mg g^{-1}).

The highest organic C in litter was in evergreen arbors (536.88 mg g^{-1}), followed by deciduous arbors (504.00 mg g^{-1}), deciduous shrubs (489 18mg g^{-1}) and evergreen arbors (441.85 mg g^{-1}). The total N in deciduous shrubs (16.03 mg g^{-1}) was higher than in evergreen shrubs (15.35mg g^{-1}); and total N in evergreen shrubs (15.35 mg g^{-1}) was higher than in deciduous arbors (12.50 mg g^{-1}). Deciduous arbors (12.50 mg g^{-1}) were higher than evergreen arbors (5.39 mg g^{-1}). There was a linear correlation between total P variations to total N among groups: the concentrations were 1.10 mg g^{-1}, 1.09 mg g^{-1}, 1.07 mg g^{-1} and 0.91 mg g^{-1}.

The concentrations of organic C, total N and total P in soils were higher in deciduous arbors, followed by deciduous shrubs, evergreen shrubs and evergreen arbors. The concentrations of organic C were 82.02 mg g^{-1}, 47.28 mg g^{-1}, 31.93 mg g^{-1} and 24.80 mg g^{-1}; and the concentrations of total N were 5.98 mg g^{-1}, 3.89 mg g^{-1}, 2.60 mg g^{-1} and 1.66 mg g^{-1}. The concentrations of total P were 0.91 mg g^{-1}, 0.65 mg g^{-1}, 0.63 mg g^{-1} and 0.41 mg g^{-1}, in these samples. The results showed that soil nutrient quality could be influenced by deciduous arbors.

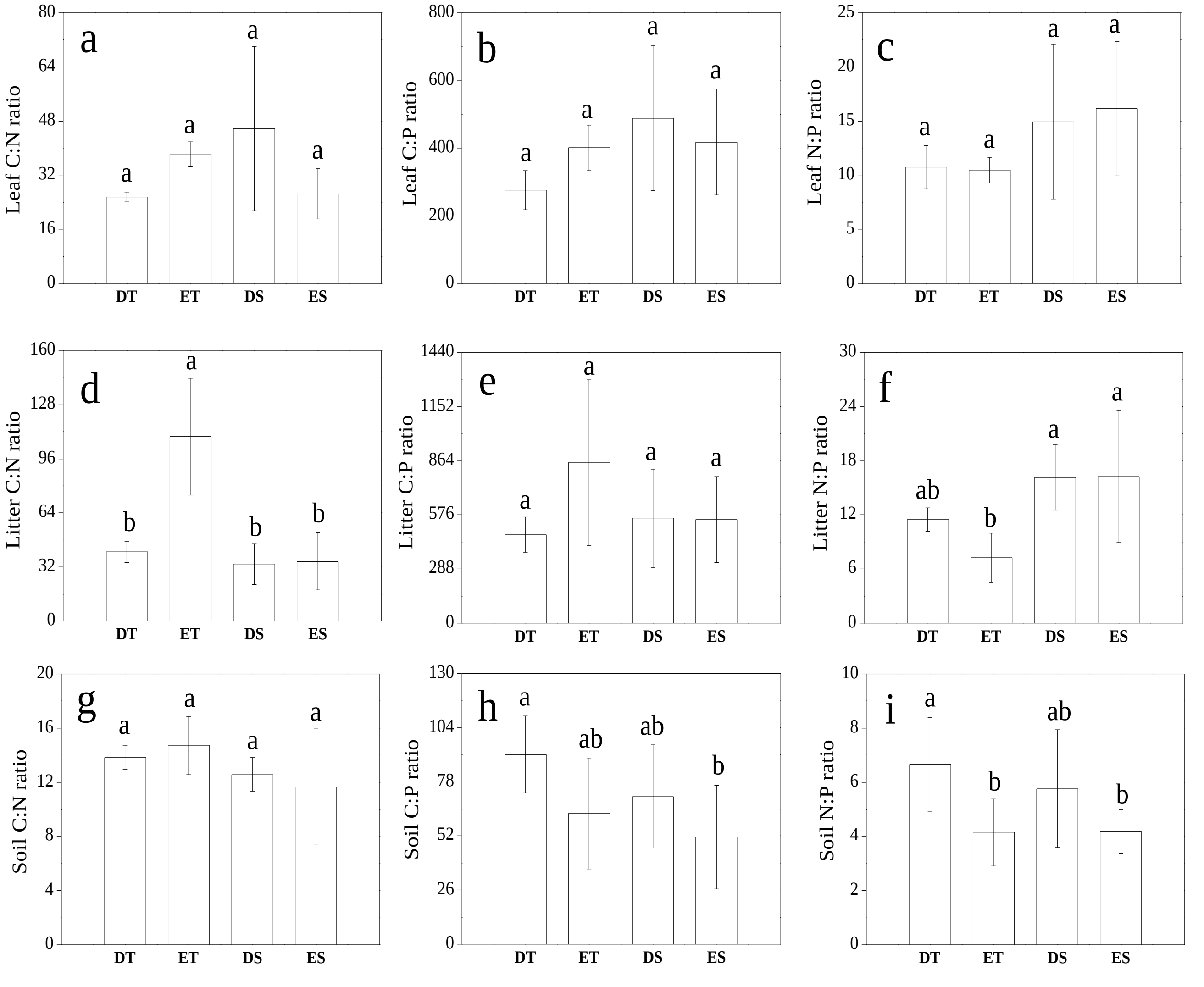

Fig. 2. Stoichiometric characteristics of C, N and P in different plant functional groups. DT, deciduous arbors; ET, evergreen arbors; DS, deciduous shrubs; ES, evergreen shrubs. Values are the mean ± standard deviation of four plant functional groups. Different letters indicate significant differences among the groups at $p<0.05$.

Stoichiometric characteristics of C, N and P in different plant functional groups: The ratio of C to N concentrations was highest in litter, followed by leaves and then soil; the ratio of N to P was similar, except in evergreen arbors (Fig. 2). The stoichiometric ratio of C, N and P was relatively high in leaves of deciduous shrubs; the C:N and C:P ratios were highest in litter from evergreen arbors, although these had less N:P ratio. The stoichiometric ratio in soils of deciduous arbors were the highest in the studied groups. The C:N ratios in leaves of evergreen arbors, deciduous arbors, evergreen shrubs and deciduous shrubs were 35.23, 25.56, 26.48 and 45.77, respectively. The C:P ratios were 488.74, 275.88, 417.89 and 291.95, respectively; and the N:P ratios were 10.46, 10.75, 16.18 and 14.93, respectively. In litter from evergreen arbors, deciduous arbors, evergreen shrubs and deciduous shrubs, the C:N ratios were 109.09, 40.95, 35.36 and 33.69, respectively; the C:P ratios were 854.64, 558.26, 550.70 and 470.63, respectively; and the N:P ratios were 7.24, 11.46, 16.26 and 16.12, respectively. In soil from evergreen arbors, deciduous arbors, evergreen shrubs and deciduous shrubs, the C:N ratios were 14.71, 13.84, 11.67 and 12.58, respectively; the C:P ratios were 62.79, 91.13, 51.44 and 70.9, respectively; and the N:P ratios were 4.14, 6.67, 4.19 and 5.76, respectively. The differences in leaf C:N ratios, C:P ratios, N:P ratios, litter C:P ratios and soil C:N ratios among plant functional groups were not significant ($p>0.05$), although significant differences were found in other stoichiometric ratios.

Relationships between C, N and P concentrations and between their stoichiometric character in different plant functional groups: The relationships between C, N and P concentrations in leaf, litter and soil from different plant functional groups are shown in Table 2. There is a significant negative relationship between organic C and total N in leaves ($p<0.05$). We also found a negative relationship between organic C in leaves and total N in litter ($p<0.01$). Positive relationships were found in total P in leaves with organic C and total N in soil ($p<0.05$). Total N and total P in leaves; total N in litter and total P in soil; organic C in soil and soil total N; soil total P, soil total N and soil total P all presented clear positive correlations ($p<0.01$).

Table 2. Correlations between C, N and P concentrations in leaf, litter and soil.

Index	Leaf C	Leaf N	Leaf P	Litter C	Litter N	Litter P	Soil C	Soil N	Soil P
Leaf C	1	-0.34*	0.20	0.87**	-0.64**	-0.26	0.06	-0.06	-0.22
Leaf N		1	0.57**	0.35	0.15	-0.05	0.31	0.39	0.38
Leaf P			1	0.28	-0.16	0.12	0.48*	0.48	0.37
Litter C				1	-0.55	-0.05	0.23	0.14	0.29
Litter N					1	-0.07	0.10	0.28	0.46**
Litter P						1	0.02	0.19	0.32
Soil C							1	0.96**	0.70**
Soil N								1	0.78**

*p<0.05, **p<0.01

Table 3. Correlations between C, N and P concentrations and stoichiometry characteristics of leaf, litter and soil.

Index	Leaf C:N	Leaf C:P	Leaf N:P	Litter C:N	Litter C:P	Litter N:P	Soil C:N	Soil C:P	Soil N:P
Leaf C	0.23	-0.01	-0.53**	0.65**	0.38	-0.50*	0.59**	0.31	0.08
Leaf N	-0.85**	-0.42*	0.46**	-0.40	-0.21	0.11	-0.31	0.16	0.32
Leaf P	-0.52**	-0.56**	-0.37*	0.08	-0.09	-0.47*	0.05	0.40	0.42*
Litter C	0.20	-0.20	-0.53**	0.55**	0.17	-0.61**	0.53**	0.34*	0.29
Litter N	-0.19	0.08	0.33	-0.87**	-0.75**	0.29	-0.62**	-0.29	-0.01
Litter P	-0.21	-0.02	0.004	-0.53**	-0.92**	-0.46*	-0.55**	-0.20	0.02
Soil C	-0.31	-0.14	-0.05	-0.27	-0.17	0.08	0.27	0.80**	0.81**
Soil N	-0.37	-0.15	-0.02	-0.38	-0.31	0.04	0.01	0.68**	0.82**
Soil P	-0.36	-0.13	0.03	-0.46*	-0.40	0.07	-0.16	0.20	0.31

*p<0.05, **p<0.01

Table 4. Correlation between leaf, litter and soil, and C, N and P stoichiometric characteristics.

Index	Leaf C:N	Leaf C:P	Leaf N:P	Litter C:N	Litter C:P	Litter N:P	Soil C:N	Soil C:P	Soil N:P
Leaf C:N	1	0.57**	-0.41*	0.12	0.19	0.07	0.26	-0.18	-0.32
Leaf C:P		1	0.37*	0.04	0.05	0.23	-0.07	-0.07	-0.05
Leaf N:P			1	-0.31	-0.07	0.48*	-0.25	-0.09	0.01
LitterC:N				1	0.76**	-0.41	0.39	0.02	-0.18
Litter C:P					1	0.21	0.44*	0.07	-0.12
Litter N:P						1	0.12	0.05	-0.02
Soil C:N							1	0.57**	0.15
Soil C:P								1	0.89**

*p<0.05, **p<0.01

Table 3 shows the correlations between C, N and P concentrations in leaves, litter and the soil continuum, and their stoichiometric characteristics among different plant functional groups. The results show that significant negative linear relationships were determined in leaf organic C and litter N:P ratio; leaf total C and leaf C:P ratio; leaf total P and leaf C:N ratio; leaf N:P ratio, litter N:P ratio, litter P and litter N:P ratio; and soil P and litter C:N ratio (p<0.05). Extremely negative linear relationships were found in leaf organic C and leaf N:P ratio; leaf total N and leaf C:N ratio; leaf total P and leaf C:P ratio; litter organic C and litter C:N ratio; soil N:P ratio, litter total N and litter C:P ratio; soil C:N ratio, litter total P and litter C:N ratio; and litter C:P ratio and soil C:N ratio (p<0.01). Positive linear relationships were determined in leaf total P and soil N:P ratios, and in litter organic C and soil C:P ratios (p<0.05); and extremely significant positive correlations were found in leaf total N and leaf N:P, litter organic C and litter C:N, soil C:N, soil organic C and soil C:P, soil N:P, soil total N and soil C:P and soil N:P ratios (p<0.01).

Table 4 shows the correlations between leaf, litter and soil continuum, and C, N and P stoichiometric characteristics among different plant functional groups. The results show that the C:N ratio and N:P ratio in leaves presented a very clear negative correlation (p<0.05). Positive N:P ratio relationships were found in leaf and soil, and also in leaf and litter. The litter C:P ratio and soil C:N ratio both presented noticeable positive correlations (p<0.05). Significant positive relationships between the C:N ratio and N:P ratio were determined in leaf, litter and soil (p<0.05). Soil C:N and N:P ratios presented extremely positive correlations (p<0.01).

Discussion

The differences in stoichiometric characteristics of C, N and P concentrations in different plant functional groups. The C, N and P concentrations, and the stoichiometric characteristics of plants, are collectively influenced by the surrounding environment and plant species, revealing the ability of plants and strategies to cope with habitats experiencing water stress (Wang & Shangguan, 2011) and indicating the limiting conditions of nutrient elements (Du *et al.*, 2011; Yamazaki & Shinomiya, 2013; Pan *et al.*, 2015). The C concentration in leaves from different plant functional groups ranged from 443 mg g^{-1} to 485 mg g^{-1}, which is 45%–50% of the internationally acknowledged average plant C concentrations (Fang *et al.*, 2015). There was a significant difference in C, N and P concentrations among plant functional groups ($p<0.5$), indicating the various abilities and strategies of different plant functional groups to adapt to their surrounding environment. Plant diversity in northwestern Guizhou, and the higher soil heterogeneity, contributed to adaptation. Higher N and P concentrations in leaves implies higher photosynthetic rates, which leads to a higher rate of plant growth and greater ability to compete for nutrients. Higher C concentrations in leaves indicates a heavier specific leaf weight; this leads to smaller photosynthetic ratio and a slower growth rate but stronger defense ability (Wright *et al.*, 2004; Pooter & Bongers, 2006). In this study the concentrations of N and P were higher in deciduous arbors and evergreen shrubs, while the organic C concentrations were relatively low, indicating the higher growth rates of these two plant types. *Rhododendron simsii* and *Populus alba* are the dominant tree species in northwestern Guizhou. They have greater resource acquisition capacity and higher utilization efficiency. Higher leaf C concentrations have also been detected in evergreen arbors, indicating their adaptation to inferior habitats by enhanced defense ability. Field research has indicated that evergreen arbors originate from another area, and have adapted to the high, cold and drought-prone habitat by enhancing their defense ability. In general, leaf N and P concentrations decrease as the amount of rain increases (Wright *et al.*, 2001; Wei *et al.*, 2011), but our research did not find this (Table 5). Future studies could be carried out to examine the reasons for this difference.

Litter degradation provides resources for forest growth and has significance in the forest ecosystem. It is also the inner component of the forest ecosystem nutrient cycle and, as a pedogenic process, is the main source of organic matter return to soil (Kang *et al.*, 2010). The C, N and P concentrations in litter from the four plant functional groups in our study were 492.98 mg g^{-1}, 12.32 mg g^{-1} and 1.04 mg g^{-1}, respectively. These values are higher in C and P but lower in N than the study on the karst area of Guangxi Province carried out by Zeng *et al.*, (2015) (Table 5). The N and P concentrations are higher than global levels while the C, N and P concentrations in leaves are below the Chinese and global levels. The C, N and P patterns in plant litter do not agree with those in plant leaves, in contrast to the results of Wang *et al.*, (2017). Further studies could be carried out on the reasons for this.

Our results also show that levels of soil organic C, total N and total P were 46.51mg g^{-1}, 3.53mg g^{-1} and 0.65mg g^{-1}, lower than the karst of Guangxi but higher than the Chinese loess plateau and the average Chinese level (Table 5). We suggested that the water and temperature conditions in northwestern Guizhou are suitable for nutrient accumulation in plants. Annual average effective accumulated temperature in northwestern Guizhou is 3 717°C, and the amount of rainfall is 863 mm. In northwestern Guangxi province, the annual average effective accumulated temperature is 6 260°C and the amount of rainfall is 1 529 mm (Zeng *et al.*, 2015), but soil nutrient concentrations in northwestern Guizhou are lower than those of the province as a whole. Organic C, total N and total P contents in northwestern Guizhou in the soil of deciduous arbors were higher than in soils of other plant functional groups ($p<0.05$). This may owing to the large amount and rapid return of litter nutrient to soils by *Rhododendron simsii* and *Populus alba*. We also suggest that the adaptive mechanisms of dominant tree species allow them to adjust high, cold and drought-prone conditions.

The N:P ratio in plant leaves is an useful indicator of nutrient limiting conditions affecting a plant at different growing stages (Wang *et al.*, 2014). Plant growth is mainly limited by N when the N:P ratio <14, but is limited by P when the N:P ratio >16. It is limited by both N and P when the N:P ratio is between 14 and 16 (Aerts & Chapin, 1990; Koerselman & Meuleman, 1996). The N:P ratio in leaves from northwestern Guizhou was 13.08, which is below the level of the karst area and the national average, but almost the same as that from the loess plateau. This suggests that N was the limiting factor in forest ecosystems in northwestern Guizhou, and may have been caused by human activity and serious soil erosion. However, there is still some argument about judging the critical dosage of limiting nutrient by using the element stoichiometric ratio (Wassen *et al.*, 1995; Güsewell & Koerselman, 2002; Ellison, 2006; Wu *et al.*, 2012). Conditions and scale of the study area need to be considered when accessing soil nutrients.

Table 5. C, N and P contents in plant, litter and soil from different plant functional groups in northwestern Guizhou, China, and some other areas.

Item	Region	C (mg g^{-1})	N (mg g^{-1})	P (mg g^{-1})	C:N	C:P	N:P	Reference
Leaf	Northwest of Guizhou in China	462.43	15.96	1.29	34.00	346.71	13.08	This study
	Northwest Guangxi in China	427.5	21.2	1.2	19.8	356	18	Zeng *et al*., 2015
	Loess plateau in China	463.2	14.97	1.14	36.69	438.78	13.30	Zhao *et al*., 2015
	China	—	18.6	1.21	—	—	16	Han *et al*., 2005
	Global	464	20.60	1.99	22.50	232	10.3	Elser *et al*., 2000
Litter	Northwest of Guizhou in China	492.98	12.32	1.04	54.77	608.56	12.77	This study
	Northwest Guangxi in China	396.2	12.7	0.9	31.4	440	14	Zeng *et al*., 2015
	Global	—	10.9	0.9	—	—	12	Kang *et al*., 2010
Soil	Northwest of Guizhou in China	46.51	3.53	0.65	13.20	69.07	5.19	This study
	Northwest Guangxi in China	92	6.4	1.5	15.3	61	4	Zeng *et al*., 2015
	Loess plateau in China	6.78	0.63	0.53	10.65	13.24	1.22	Zhao *et al*., 2015
	China	11.2	1.1	0.7	10-12	136	9.3	Tian *et al*., 2010
	Global	—	—	—	14.3	186	13.1	Zhao *et al*., 2015

Note: "—", no relevant data found

N:P ratio is important in influencing the degradation of litter and the speed of nutrient return. Litter degradation is easier at lower N:P ratios. The degradation of litter is slow when the litter N:P ratio is greater than 25, which is suitable for nutrient storage (Pan *et al.*, 2011). The N:P ratio in litter from northwestern Guizhou was 12.77, indicating its importance in enhancing the ecosystem function of the litter in mitigating soil erosion and retaining soil moisture. To optimize the stand structure, it is necessary to build a bush layer: the arbor and shrub mixed forest that forms afterwards can increase the N:P ratio in the litter. In litter, the C:P ratio was greater than the C:N ratio and then of the N:P ratio. This indicates less N content of the plants in northwestern Guizhou. The C:P and C:N ratios were higher in the litter than in leaves, but have similar N:P ratio. One reason for this may be the weak transference ability of N and P in plants when winter senescence dormancy takes place. The uptake mechanism of N and P in different plant groups, however, needs to be studied further.

There was a negative correlation between the soil C:N ratio and its degradation speed, which shows a fast mineralization in soil when the C:N ratio is low (Han *et al.*, 2005). In this study, it can be seen that the mineralization rate in deciduous arbor soil in northwestern Guizhou was faster than that of soil in the evergreen arbor, resulting from the slow decomposition of leaves. The high validity of P can be seen in the lower C:P ratio (Wang & Yu, 2008), which has an important influence on plant growth. The differences in C:P ratios in soils were not significant in different plant functional groups in northwestern Guizhou, showing a similar level of effect of the soil P element in this area. This may due to the slower rock weathering and migration rate of the P element. Also, plots in the study area were close to each other, which may have caused the insignificant differences. We found higher C:P ratios compared with those from the karst area of Guangxi and loess plateau, but ratios were still below average Chinese and global levels. Although soil P validity in this area exceeded part of the degradation ecosystem, it was still below average Chinese and global levels. The soil N:P ratio can be used as an effective predictor of the type of nutrient limitation. There are significant differences in soil N:P ratios from different plant functional groups in northwestern Guizhou, indicating the variations in nutrient limitation types of the different plant functional groups. The lower levels of N and P in soils from the studied areas suggest that there were some limitations in soil N and P nutrients in the areas we examined.

C, N and P contents in the different plant functional groups and their correlations with stoichiometry characteristics. Plant, part of the foundation of land ecosystem, play an important role in regulating the stability of that ecosystem. The elements C, N and P are essential for plant growth and have prominent functions in plant growth and behavior processes. Leaf, litter and soil, which represent biotic and plant factors in the ecosystem, are sensible to changes in the environment (Liu *et al.*, 2010). The differences are determined by their different function of soil and plant (Yang *et al.*, 2014) and their varying C, N and P ratios. This study found significant correlations among N and P content in plant leaf and soil in northwestern Guizhou (p<0.01). A linear correlation between N and P contents in plants and in soil was reported by Xiao *et al.*, (2014). However, this study found no significant correlation between C, N and P contents in leaves and those in soil (Table 3); this is comparable to the stoichiometry in Tianshan, China (Xie *et al.*, 2016). The differences observed may be due to the impact of, for example, plant species, growth, group characteristics, soil type, ecosystem or human activities on the content of elements in plants (Yu *et al.*, 2014).

Zeng *et al*., (2015) reported that the C:N and C:P ratios are higher in litter than in plants and soil, which is comparable to this study. In this study, significant linear correlations (p<0.01) of leaf total N and total P have been found in leaves of various plant species. C, N and P content and their stoichiometry ratios have strong relationships with each other (Wu *et al.*, 2010). This indicates that different plant functional groups adapt to environment changes by adjusting the function of different modules and their correlations with suitable adaptation strategies (Qi *et al.*, 2016).

There was a significant impact of C and N in leaves and litter on soil C:N:P ratio stoichiometry characteristics. This indicates the contributions of forest ecosystem nutrients returning and self-fertilizing the ecosystem. The forest plants we studied in northwestern Guizhou are seriously influenced by human activities such as fencing grassland, cutting firewood, deforestation and reclamation. In addition, our results show that there were fewer influences of soil on the C:N:P ratio of the different plant functional group stoichiometry characteristics.

This study only considered the differences in C, N and P nutrient change and its stoichiometry characteristics from various plant functional groups. It is still necessary to study the influence of temperature, humidity, solar radiation, human activities, topography, and so on, on ecological stoichiometry characteristics, combined with Ca, S (Edward *et al.*, 2016) and K (Wang & Tim, 2014), in order to appraise forest ecosystem nutrient limitation law and circulation law in northwestern Guizhou. Taking the special variations into consideration may assist the study of relationships among forest ecosystems and their inner relationships (Elser *et al.*, 2000).

Conclusions

Low nutrient content was determined in leaves and soil of different plant functional groups in Guizhou, China, an area where N is the limiting element for plants. In general, deciduous arbors can take up nutrients from the environment, while evergreen arbors can adjust their living conditions by enhancing nutrient release. Evergreen arbors and deciduous shrubs are both helpful in maintaining soil nutrients. No correlations have been found between the nutrient contents in soils and those in leaves, indicating the influences of multiple factors on the content of elements in plants. Absence of the influence of soil on the stoichiometric characteristics of plant functional groups indicates that some activities such as closing hills for afforestation could be carried out in this area to protect plants.

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