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Ecological stoichiometry characteristics in leaf-litter-soil system in dominant species of trees, bushes and grasses in the secondary forest area of the Chinese Loess Plateau

Zongfei Wang [1, 2] , **Fenli Zheng** Corresp. [1, 3]

[1] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, China
[2] University of Chinese Academy of Sciences, Beijing, China
[3] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, China

Corresponding Author: Fenli Zheng
Email address: flzh@ms.iswc.ac.cn

Ecological stoichiometry can reveal interactions between soil, plants and their nutrient cycle in ecosystems. However, currently there is litter information related to ecological stoichiometry characteristics in leaf-litter-soil systems of dominant grasses, bushes and trees and their intrinsic relationship during vegetation restoration. Thus, this study selected three dominant plant types of grasses (*Imperata cylindrica* (*I. cylindrica*) and *Artemisiasacrorum* (*A.sacrorum*)), bushes (*Sophora viciifolia* (*S. viciifolia*) and *Hippophae rhamnoides* (*H. rhamnoides*)) and trees (*Quercus liaotungensis* (*Q. liaotungensis*) and *Betula platyphylla* (*B. platyphylla*)) in the secondary areas of the Chinese Loess Plateau to investigate ecological stoichiometric characteristics in leaf-litter-soil systems and their intrinsic relationships. The results indicated that plant community type had significant effects on the nutrient concentration (C, N and P) and their ratios in leaf, litter and soil. N concentration and N:P ratios in leaf and litter were highest in shrub community type than that in other two communities; leaf P concentration in grass community was highest and litter in forest community type had the highest P concentration. Soil C, N and P concentrations were highest in forestland ($P < 0.05$) and they declined with soil depth. Furthermore, the relationship between the N concentration in soil and leaf and litter was not significant ($P > 0.5$), but the soil P concentration was significantly correlations with litter P concentration ($P < 0.05$). Based on the theory that leaf N:P ratio indicates nutritional limitation for plant growth, this study proposed that shrub community type growth was limited by P element, and growth of grass and forest community types was limited by N and both of N and P elements, respectively. These findings enhance understandings of nutrient limitations in different plant communities during vegetation restoration and provide insights for better management of restoration.

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Zongfei Wang[1,2], Fenli Zheng[1,3]

[1] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, CAS & MWR, Yangling, Shaanxi 712100, PR China;
[2] University of Chinese Academy of Sciences, Beijing 100049, PR China
[3] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, PR China

Corresponding author: Prof. Fenli Zheng
E-mail: flzh@ms.iswc.ac.cn

ABSTRACT

Ecological stoichiometry can reveal interactions between soil, plants and their nutrient cycle in ecosystems. However, currently there is ~~litter~~ information related to ecological stoichiometry characteristics in leaf-litter-soil systems of dominant grasses, bushes and trees and their intrinsic relationship during vegetation restoration. Thus, this study selected three dominant plant types of grasses (*Imperata cylindrica* (*I. cylindrica*) and *Artemisia sacrorum* (*A. sacrorum*)), ~~bushs~~ (*Sophora viciifolia* (*S. viciifolia*) and *Hippophae rhamnoides* (*H. rhamnoides*)) and trees (*Quercus liaotungensis* (*Q. liaotungensis*) and *Betula platyphylla* (*B. platyphylla*)) in the ~~secondary areas~~ of the Chinese Loess Plateau to investigate ecological stoichiometric characteristics in leaf-litter-soil systems and their ~~intrinsic relationships~~. ~~The results indicated that plant community type had significant effects on the nutrient concentration (C, N and P) and their ratios in leaf, litter and soil. N concentration and N:P ratios in leaf and litter were highest in shrub community type than that in other two communities; leaf P concentration in grass community was highest and litter in forest community type had the highest P concentration. Soil C, N and P concentrations were highest in forestland ($P<0.05$) and they declined with soil depth. Furthermore, the relationship between the N concentration in soil and leaf and litter was not significant ($P>0.5$), but the soil P concentration was significantly correlations with litter P concentration ($P<0.05$),~~ Based on the theory that leaf N:P ratio indicates nutritional limitation for plant growth, this ~~study proposed that shrub community type growth was limited by P element,~~ and growth of grass and forest community types was limited by N and both of N and P elements, respectively. These finding enhance understandings of nutrient limitations in different plant communities during vegetation restoration and provide insights for better management of restoration.

Key words: Plant community type; Leaf-litter-soil; Ecological stoichiometry; Nutrient elements; Nutrient limitation

Abbreviations: *Quercus liaotungensis*: *Q. liaotungensis*; *Betula platyphylla*: *B. platyphylla*;

Sophora viciifolia: *S. viciifolia*; *Hippophae rhamnoides*: *H. rhamnoides*; *Imperata cylindrica*: *I. cylindrica*; *Artemisia sacrorum*: *A. sacrorum*; Organic carbon: C; Total nitrogen: N; Total phosphorus: P

INTRODUCTION

Currently, soil erosion has become a major global environmental problem, accelerating soil nutrient losses and ecosystem degradation (*Luque et al., 2013*). At present, vegetation restoration or rehabilitation is a powerful approach for the ecological restoration of degraded lands, as it can control soil erosion and improve ecosystem functions and services (*Godefroid et al., 2003; Zheng, 2006; Jiao et al., 2012; Sauer et al., 2012; Zhao et al., 2015; Bienes et al., 2016*). Moreover, vegetation restoration can affect the plant community composition and species diversity (*Wang et al., 2011*), which results in changes in nutrients distribution in leaves, litter and soil (*Parfitt, Yeates & Ross, 2005; Hobbie et al., 2006; John et al., 2007; Jiao et al., 2013; Zhao et al., 2017*). In particular, several plant communities show significant differences in nutrient allocation ~~throughout vegetation restoration~~ (*Warren & Zou, 2002; Schreeg et al., 2014; Deng et al., 2016*). Therefore, it is necessary to quality nutrient characteristics in the leaf-litter-soil system of dominant grasses, bushes and trees, as well as their intrinsic relationships during vegetation restoration.

Ecological stoichiometry describes the balance of energy and multiple chemical elements in ecosystems (*Elser et al., 2000*), and has gradually become a method for studying the stability and N/P limitation of degraded ecosystems (*Güsewell, 2004; Han et al., 2005*). Meanwhile, it is also an effective tool to study the interaction between soil and plant, and their nutrient cycles (*Elser, 2006*). C, N, and P cycles account for the transfer of nutrients between plant and soil. ~~C is a structural substance~~, approximately supplying 50% of the dry biomass, whereas N and P are the major limiting elements of natural terrestrial ecosystems and play important roles in several physiological and metabolic processes. These three nutrients interact with each other, and both N and P affect carbon fixation (*Han et al., 2005*). The notion that leaf N:P ratio can be used to identify nutrient limitation for plant growth has been widely confirmed in various plant communities (*Koerselman & Meuleman, 1996; Schreeg et al., 2014*). Thus, the analysis of the ecological stoichiometric characteristics of leaf-litter-soil systems is of theoretical and practical relevance.

Soil property has a major influence on the structural and functional composition of a plant community, as well as on its succession and species diversity (*Fu et al., 2010; Wang et al., 2011*). On the other hand, plants help maintain the elements stability of an ecosystem, such as carbon is fixed through photosynthesis, and nutrients are gradually returned to the soil in the form of the litter. In the plant-soil ecosystem complex, and ~~litter serves as the basic carrier of nutrients~~, linking between plants and soil (*Agren & Bosatte, 1998*). The litter layer provides storage for ecosystems nutrients and acts as a hub for material exchange between soil and plants, and is a natural source of soil fertility (*Agren et al., 2013*). Nutrient supply in soil, plant growth demand, and litter return into soil are nominally independent factors, but also, they interact with each other which leads to the complex research on nutrient concentration in the plant-litter-soil systems (*Agren & Bosatte, 1998*). Ecological stoichiometry provides an effective approach for observing the relationships between nutrients in the plant-litter-soil systems and their characteristics in ecological processes (*Elser et al., 2000*).

Due to its steep topography and erodible soil, coupled with long-term human activity, the ecological environment of the Loess Plateau is extremely fragile, and has become one of the most severely eroded areas of China (*Jiao et al., 2012; Zhao et al., 2015*). In the past decades, the majority of forestlands were destroyed to satisfy the food needs of the growing population, which has resulted in severe soil erosion and land degradation. The Grain to Green Program (GTGP) was implemented to control soil erosion and improve ecosystem degradation, with a main goal of converting low-yield steep-slope croplands into permanent vegetation cover (*Jiao et al., 2012; Zhao et al., 2015*). The vegetation restoration generated a diverse flora and reduced soil erosion, raising interest in the characterization of this recovering ecosystem. For example, *An & Shangguan (2010) and Chai et al. (2015)* studied leaf stoichiometric traits and concluded that the growth of vegetation was N-limited at each secondary successional stage, according to the leaf N: P threshold. *Ai et al. (2017)* observed that the slope aspect had various effects on plant and soil C: N: P stoichiometry, where different vegetation types influenced soil C: N: P stoichiometry and ratios ~~were higher~~ in afforested lands than that in slope croplands (*Zhao et al.,* *2015; Deng et al., 2016; Zhao et al., 2017*). *Jiao et al. (2013)* studied vegetation successional changes in soil stoichiometry and reported that soil N: P ratio increased with the vegetation restoration year. Even the ~~forest growth time~~ was reported to have a significant effect on C, N, P and K concentrations and their ratios in plant tissues and soil (*Li et al., 2013*). Summarily, most previous studies addressed the stoichiometric characteristics of the soil system or the vegetation communities, including forests and grasslands, as well as litter individually or in both. However, the ecological stoichiometry of the plant-litter-soil system as a whole has so far been rarely described (*Zeng et al., 2017; Cao & Chen, 2017*), and the effects of dominant plant communities (tree, shrub, grass) during vegetation restoration on this ecological stoichiometry remains poorly understood. Therefore, it is necessary to study such stoichiometry characteristics and their relationships in leaf- litter- soil system of dominant grass, bush and tree during vegetation restoration. This will provide a better understanding of nutrient limitation in different plant communities during vegetation restoration and improve ecosystem management. In addition, since, the majority of previous studies have focused on topsoil (*Jiao et al., 2013; Li et al., 2013; Zeng et al., 2016; Zeng et al., 2017*), there is litter information on stoichiometry change with the soil profile (*Zhao et al., 2015, Deng et al., 2016*). Due to the depth of thick loess on the Loess Plateau, the majority plant roots are distributed within the top100 cm. Therefore, it is important to investigate change of the stoichiometry of C, N and P with soil profile.

Three dominant plant~~s~~ communities of grasses (*Imperata cylindrica* and *Artemisia sacrorum*), bushs (*Sophora viciifolia* and *phae rhamnoides*) and trees (*Quercus liaotungensis* and *Betula platyphylla*) were selected in the Ziwuling secondary area of the Loess Plateau to investigate ecological stoichiometry in the plant-litter-soil system and their intrinsic relationships. The specific objectives of this study were to 1) determine leaf and litter C, N and P concentrations and their ecological stoichiometry characteristics in three dominant plant types; 2) investigate distribution of soil C, N, and P concentrations and ecological stoichiometry characteristics in soil profile; 3) ~~analyze the relationships of ecological stoichiometry in leaf-litter-soil system (C, N, and P)~~; and 4) assess the limiting nutrient element for plant growth in all three dominant plant types. The effort will provide information about ecological stoichiometry and theoretical support for enhancing vegetation and ecosystem restoration on the Loess Plateau.

MATERIAL AND METHODS

Study site description

This study site was located at Fuxian County, Shanxi Province, China (35°5.4′ N, 109°8.9′ E), in the center of Loess Plateau, south of the Yan'an city. The topography and landform belong to loess hilly-gully region with elevation ranging from 920 to 1683 m (*Zheng, 2006*). The mean annual temperature ranges from 6 to 10°C and mean annual precipitations are between 600 to 700 mm. The soil is mainly composed by loess, which can be classified as a Calcic Cambisol (*USDA NRCS, 1999*). The soil texture was 28.3% sand (> 50 μm), 58.1% silt (50–2 μm) and 13.6% clay (< 2 μm). Especially, in this area, vegetation was completely destroyed more than 100 years ago and ~~that time soil intensity was~~ 8,000 to 10,000 t km^{-2} yr^{-1} (*Zheng et al., 1997; Kang et al., 2014*). ~~Since 1862-1874, due to inter war and population was more out and vegetation start to restoration~~. Currently, forest canopy closure is more than 0.6 and dominant species for tree are *Quercus liaotungensis* (climax forest community) and *Betula platyphylla* (early forest community); two dominant species for shrub are *Sophora viciifolia* and *Hippophae rhamnoides*, both does not concur in same places; and main herb species are *Imperata cylindrica* and *Artemisia sacrorum* (*Zheng, 2006*).

Soil and plant sampling

First of all, a field survey was conducted in order to select sampling sites. Then, three dominant plant types, trees (*Q. liaotungensis* and *B. platyphylla*), shrubs (*S. viciifolia* and *H. rhamnoides*) and grasses (*I. cylindrica* and *A. sacrorum*) were selected for this study. For each plant type, three experimental sites with a similar site condition including slope, altitude, and aspect, were set up to collect samples. All experimental sites were within approximately 1.5 km. Plant leaves and soil samples were collected in late July 2016 when plants were in a vigorous growth period, and the litter samples with over multiple years on the soil surface but not decomposed were obtained in late October 2016. Table 1 shows the characteristics of these three plant communities.

Three plots with 20×20 m were selected from each sampling site of forest type, whereas the plots sizes chosen for shrub and grass types were 5×5 m and 1×1 m, respectively. Ten to twenty complete expanded and sun-exposed leaves were randomly collected from five to ten healthy individual plants per plot from shrubs or trees, and a total of 80 to 100 samples were collected. For each grass plot, all stems and leaves were completely cut from three 0.25 m^2 sampling areas. Leaves from each plot were evenly mixed and then put into a paper bag. Litter samples were collected along the diagonal lines of three 1 x 1 m squares per plot, and mixed and stored in paper bags. Later on, all samples of leaves and litter were carried back to the indoor laboratory for analysis.

Soil samples from a 100 cm-depth profile were collected using a 5-cm diameter to collect soil samples along an S-shaped line in each plot. Before each soil sample was collected, soil sampler was sterilized with ethanol to avoid cross-infection. The 100 cm soil profile was divided into six layers (0-10, 10-20, 20-40, 40-60, 60-80, 80-100 cm), then five points samples were collected from each depth, then soil samples from each layer were mixed evenly and stored in a plastic bag.

Table 1

Sample analysis

Leaf and litter samples were oven dried at 70 °C for at least 48 h or more to reach a constant mass level, and then weighed. Dried plant samples were ground to a fine powder using a plant-sample mill (1093 Sample Mill, Foss, Sweden). Soil samples were air-dried and sieved using a 0.25 mm mesh. To determine C concentration in plant and soil, the Walkley-Black modified acid-dichromate $FeSO_4$ titration method was used (*Bao, 2000*), whereas the Kjeldahl method (KJELTE2300, Sweden) was applied to measure the total N concentration in plant and soil. The Mo-Sb colorimetric method was used to analyze total P concentration in plant by using a

Spectrophotometer UV-2300 (Techcomp Com, Shanghai, China), and the total P concentration in soil was determined with the same spectrophotometric method with extraction with $HClO_4$-H_2SO_4 (*Bao, 2000*). Leaf, litter and soil C, N, P concentrations were expressed as g/kg on dry weight basis. The C: N: P ratios in leaves, litter and soil were computed as mass ratios.

Statistical analysis

All data are presented as mean ± standard errors and tested for normality of distributions and homogeneity of variances before analysis. A one-way analysis of variance (ANOVA) was used to analyze the effects of the plant type on nutrients and stoichiometric characteristics in leaf, litter and soil. Pearson's correlations were used to assess the correlation between leaf and litter nutrient concentrations and their ratios, as well as the corresponding values in the soil. Differences were considered significant with a $P<0.05$. All statistical analyses were determined with SPSS 19.0 software (SPSS, Inc., Chicago, IL, USA).

RESULTS

Leaf and litter nutrients and ecological stoichiometry in dominant plant communities

The leaf C, N and P concentrations ~~responded differently to~~ different plant communities (Table. 2). The C concentration in leaf varied from 475.02 (grass) to 522.20 g/kg (forest), and it was highest in *B. platyphy*lla and lowest in *A. sacrorum*. The leaf N concentration was 29.83 g/kg in shrub, and was significantly greater than that in forest and grass ($P<0.05$), while the leaf P concentration with 1.80 g/kg was highest in grass. The leaf C:N ratio varied from 16.85 (shrub) to 47.30 (grass), and was highest in *I. cylindrica* and lowest in *H. rhamnoides*. The leaf C:P ratio was significantly higher in *Q. liaotungensis* and *S. viciifolia* than other species ($P<0.05$). The leaf N:P ratio varied from 6.12(grass) to 22.59 (shrub) and it was significantly higher in shrub than that in grass and forest ($P<0.05$).

The C, N and P concentrations in litter were significantly affected by plant types (Table. 3). The litter C concentration varied from 360.08 (shrub) to 412.93 (forest), and it was significantly higher in forest than those in grass and shrub ($P<0.05$). N concentrations showed a similar pattern between litter and leaf, and were significantly highest in shrub (*P*<0.05). The litter P concentration varied from 0.51 (grass) to 0.97 g/kg (forest) and it was highest in *B. platyphy*lla and lowest in *I. cylindrica*. The litter C:N and C:P ratios in grass were 52.93 and 734.59, respectively, and they were significantly higher than those in forest and shrub (*P*<0.05). The litter N:P ratio varied from 12.52 (forest) to 24.16 (shrub), and it was highest in *H. rhamnoides* and lowest in *B. platyphy*lla (*P*<0.05).

Table 2

Table 3

Soil nutrients and ecological stoichiometry in dominant plant communities

~~The majority of the differences in soil nutrients between different plant types and soil layers were significantly different~~ (Table. 4). Soil C and N concentrations in forestland were greater than those in shrubland and grassland at all the soil depth and it was highest in *Q. liaotungensis* and lowest in *A. sacrorum* (*P*<0.05). Overall, in all plant communities, the highest soil C and N concentrations in *Q. liaotungensis* were 21.91 and 1.83 g/kg, respectively, which were found in the top soil (0-10 cm), and soil C and N concentrations decreased markedly from 10 to 40 cm of soil depth, and then slightly decreased from 40 to 100 cm. Soil P concentration in shrubland was lower than those in grassland and forestland at every soil depth (*P*<0.05), and it was lowest in *H. rhamnoides* and highest in *B. platyphy*lla, there were no differences in *B. platyphylla*, Q. liaotungensis and A. sacrorum at 20-100 cm soil layers. The highest soil P concentration in *B. platyphyll* was 0.74 g/kg, which was found in the top soil (0-10 cm), and along the profile, soil P concentration had a narrow variation in all plant communities. The soil C:N ratio in forestland was significantly higher than that in shrubland and grassland at the 0-10 and 10-20 cm soil depths (*P*<0.05), but there were no significant differences at other soil depths (*P*>0.05). In general, soil C:N ratio in all plant communities fluctuated with increasing of soil depth. Soil C:P and N:P ratios in forestland was significantly higher than ~~that~~ in shrubland and grassland at the 0-10 and 10-20 cm soil depths (*P*<0.05), but there were highest in shrubland in other soil depths

($P<0.05$). Overall, in all plant communities, the largest soil C:P and N:P ratios in *Q. liaotungensis* were 31.54 and 2.64, respectively, which were observed in the top soil (0-10 cm), and soil C:P and N:P ratios significantly decreased within 0-40 cm soil depths, and then they slowly changed from 40 to 100 cm soil depth

The soil sampling depth had significantly affected the soil nutrients and their ratios (Fig 1). Soil C and N concentrations significantly decreased along the soil sampling depth, and the largest values of soil C and N concentrations were observed in *Q. liaotungensis* and decreased from 21.90 to 6.49 g/kg and from 1.83 to 0.63 g/kg, respectively. Soil P concentration tend to stable along the soil sampling depth. Soil C:N fluctuated along the soil sampling depth, and the highest values were found in *Q. liaotungensis* at 0-20 cm soil sampling depth. Soil C:P and N:P ratios had the same varied trend along the soil sampling depth and the largest values were observed in *Q. liaotungensis* and decreased from 31.54 to 6.28 and from 2.64 to 0.64 g/kg, respectively.

Table 4

Figure 1

Relationships between C, N and P concentrations and their characteristics of ecological stoichiometry among leaf, litter and soil

There were significant correlations between leaf and litter for both N and P concentrations in three plant community types ($P<0.05$) (Fig 2b, c). The relationships between the plant C concentration and soil C concentration were significant in three soil layers (0-10, 0-20 and 0-100 cm) ($P<0.05$) (Fig 3a, b, c and Fig 4a, b, c), while there were no significant correlation between plant and soil N concentration (Fig 3d, e, f and Fig 4d, e, f). In three plant community types, there were no significant correlation between leaf P concentration and soil P concentration (Fig 3g, i), but the soil P concentration was significant correlated with litter P concentration in 0-10 cm soil depth ($P<0.05$) (Fig 3h). In the 0-10 cm soil depth, N concentration in leaf increased linearly with the increase of the soil N concentration ($r^2=0.94$ and $P<0.05$ for grass community type; $r^2=0.342$ and $P<0.05$ for forest community type) (Fig 5g and 7g). The litter N concentration was correlated with soil N concentration in grass community type (Fig 5j). Furthermore, the leaf P was linearly correlated with the soil P concentration ($r^2=0.4185$ and $P<0.05$ for grass community type; $r^2=0.7104$ and $P<0.05$ for shrub community type; $r^2=0.5872$ and $P<0.05$ for forest community type)) (Fig 5n,6n and 7n). The litter P concentration was correlated with soil P concentration in forest community type (Fig 7q). In the 0-20 cm soil depth, N concentration in leaf and litter increased linearly with the increase of the soil N concentration ($r^2=0.8661$ and $P<0.05$, and $r^2=0.9012$ and $P<0.05$ for grass community type; $r^2=0.4385$ and $P<0.05$, and $r^2=0.4284$ and $P<0.05$ for forest community type) (Fig 5h, k and 7h, k). Furthermore, the leaf P concentration was linearly correlated with the soil P concentration ($r^2=0.4817$ and $P<0.05$ for grass community type; $r^2=0.8138$ and $P<0.05$ for shrub community type; $r^2=0.7101$ and $P<0.05$ for forest community type)) (Fig 5o, 6o and 7o). In the 0-100cm soil depth, the leaf P concentration was linearly correlated with the soil P concentration ($r^2=0.8631$ and $P<0.05$ for shrub community type; $r^2=0.58$ and $P<0.05$ for forest community type)) (Fig 6p and 7p) and litter P concentration was linearly correlated with the soil P concentration ($r^2=0.6592$ and $P<0.05$ for grass community type; $r^2=0.4628$ and $P<0.05$ for forest community type)) (Fig 5s and 7s).

For three plant community types, leaf C:N and N:P ratios were positively correlated with litter C:N and N:P ratios, respectively ($P<0.05$) (Fig 2d, f), while leaf C:P ratio was negatively correlated with litter C:P ratio ($P<0.05$) (Fig 2e). Meanwhile, leaf C:P had a positive correlation at with soil C:P ratio at the 0-10 and 0-100 cm soil layers ($P<0.05$) (Table 5), and leaf N:P ratio had a positive correlation with soil N:P ratio at three soil layers ($P<0.05$) (Table 5), and there was significant correlation between leaf and soil C:N ratio at the 0-10 and 0-100 cm soil layers ($P<0.05$) (Table 5). At the 0-10cm soil layers, there was significant correlation between litter and soil C:N ratio ($P<0.05$) (Table 5), and in the three soil layers, litter C:P ratios were negatively correlated with C:P ratios, while only in the 0-100 cm soil layers, litter N:P ratio had a positive correlation at with soil N:P ratio ($P< 0.05$) (Table 5).

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Table 5

DISCUSSION

Impacts of dominant plant communities on leaf and litter nutrients and ecological stoichiometry

As a key subsystem, plants have a vital function in governing the stability of terrestrial ecosystem. C, N and P are essential nutrients for plant (*Han et al., 2005; John et al., 2007*) and their interaction regulates plant growth (*Güsewell, 2004*). The decomposition of plant litter ~~replenish~~ soil nutrients to provide conditions for the adjustment and demand of the plant nutrients (*Agren & Bosatte, 1998*). Most studies reported that leaf C, N and P concentrations differed across plant communities (*Schreeg et al., 2014; Zeng et al., 2017*). The reason was that different plant communities has different adaptability to the environment, and possess different strategies of nutrient adaptation (*Wright et al., 2004*). In this study, leaf C concentration in forest species was significantly higher than that in grass and shrub species, while the leaf P in forest species was significantly lower than that in grass species. An explanation may be that a large part of nutrients absorbed by trees is used to construct a protective structure, while grasses have a short life span, and high photosynthetic capacity and nutrient efficiency. The results are consistent with those of *Wright et al. (2004)*, which reported that the leaf P concentration in herbaceous plants is significantly higher than that in woody plants. Furthermore, the higher leaf N concentration observed in shrub was probably due to presence of legumes (*S. viciifolia* and *H. rhamnoides*), because there were nitrogen-fixing plants which can utilize atmospheric N_2.

Moreover, in this study, the C, N and P concentrations in plant leaves were higher than those in the corresponding litter, which was consisted previous studies (*Pan et al., 2011; Zeng et al., 2017*). *Pan et al. (2011)* showed that the C, N and P concentrations in the leaves of trees, shrubs and grasses were significantly higher than those in litter, likely due to the reabsorption processes. Previous studies have shown that nutrients present in leaves are transferred to flowers, fruits, branches, and roots before leaf falling, thereby preventing nutrients loss (*Schreeg et al., 2014*). The litter N and P concentrations varied greatly in different plant communities, and were significantly higher in trees and shrubs than those in grasses. This is because tree and shrub are deep-rooted plants, and have the strong capability of absorbing nutrients from multiple sources in environment, while grass has shallow roots and relies more on the recycling of their own nutrients.

N and P elements are major limiting factors for plant growth in terrestrial ecosystems, and the leaf N:P ratio could be used as an indicator to identify the limiting nutrient factors (*Koerselman & Meuleman, 1996; Güsewell, 2004*). However, the threshold of N:P ratio is affected by the difference of study area, plant growth stage and plant species (*Güsewell, 2004*). *Güsewell (2004)* reported that leaf N:P ratio between 10 and 20 was used as a threshold to assess a limitation of plant growth. If the N:P ratio was > 20, plant growth was limited by P; if the N:P ratio was < 10, plant growth was limited by N. When the N:P ratio was between 10 and 20, plant growth was limited by both P and N together. In this study, the leaf N:P ratio in *S. viciifolia* was 23.27, suggesting that its growth was P-limited. Meanwhile, the leaf N:P ratios in *Q. liaotungensis*, *B. platyphylla* and *H. rhamnoides* were 14.35, 12.91 and 17.34, respectively, indicating that their growths were co-limited by N and P. The leaf N:P ratios in *A. sacrorum* and *I. cylindrica* were 6.11 and 9.92, respectively, indicating that grass growth was limited by N. The results indicated that different plant communicates had different nutrient limiting elements, which is consisted with previous studies (*Han et al., 2005*). In this study, grass species (*I. cylindrica* and *A. sacrorum*) is a shallow-rooted plant with a strong ability to absorb soil surface nutrients, particularly P element and it has a greater capacity of relocating its leaf P before leaf falling than that of forest and shrub species, and it can more effectively utilize leaf P concentration to meet growth demands. Therefore, grass species were less limited by P element than that by N element. In addition, the results indicated that the growth of shrub species was limited by P element, which was similar to results reported by *Han et al. (2005)*. This is because shrub species was nitrogen-fixing plants, and their absorptions of N element are much greater than that the P element, resulting in a lack of P element in shrub specie. The leaf C:N ratio and C:P ratios for three plant communities showed an ability to assimilate C based on nutrient reabsorption, reflecting utilization efficiency and suggesting a significant bearing on community ecology (*Aerts, 1996*). This result also reflected C efficiency of different plant communities, as the accumulation rate and storage capacity of C was related to both N and P supplies, which limited plant growth (*Herbert, Williamns & Rastetter, 2003*). The leaf C:N, N:P and C:P ratios differed in plant communities, as determined by peculiar characteristics and nutrient use efficiency of each plant species (*Koerselman & Meuleman, 1996*). Moreover, the grass specie had the lower N:P ratios than that in forest and shrub species, indicating that it has a higher growth rate, which was consisted with previous studies (*Agren, 2008*). Leaf C: N and C: P ratios were lower than those in litter, which is consistent with results reported by *McGroddy et al. (2004)*, indicating that the reabsorption capacity for C is lower than that for N and P. If the leaf N:P ratio will be used as an index to evaluate both N and P nutrient supplies in the Loess Plateau, its limitations should to be first evaluated, and it should be combined to fertilization tests for further diagnosis.

Impacts of dominant plant communities on soil nutrient and ecological stoichiometry

Plants play an important role in improving soil fertility and contribute to the accumulation of soil nutrients. *Fu et al. (2010)* found that vegetation restoration could improve the net fixation of C and N because this process can reduce their loss. However, the performance in soil quality recovery differed among plant communities (*Jiao et al., 2012; Zeng et al., 2016*). This study showed a difference in soil nutrients between plant communities, which is consistent with previous findings (*Deng et al., 2016; Zhao et al., 2017*). This may be correlated to a variation in activity and dependent on root depth, both factors would lead to differences in nutritional availability. In this study, soil C concentration in forestland was greater than that in grassland and shrubland, and is consistent with the previous results of *Jiao et al. (2012)* and *Qi et al. (2015)*. This result could be explained by a larger amounts of litter present in forestland, a more above-ground litter and a higher volume of root exudates reaching the soil, which would collectively increase the soil C concentration. The soil N concentration followed a similar trend as the soil C concentration in all plant communities, which is easily explained by the fact that over 99 % of the soil N was derived from organic matter. Thus, the increasing of soil C concentration could have indirectly increased N concentration. In general, in forestland, soil P concentration at 0-100 cm depths was higher than that in shrubland and grassland. Moreover, soil C and N concentrations decreased with increasing of soil depth, while soil P concentration was relatively stable, which was consistent with *Wei et al. (2009)*. The reason might be that besides the influence of soil parent material, soil C and N concentrations were also affected by the amount of returning litter, the rate of decomposition, and by plant absorption and utilization. With the increasing of the soil depth, the input of organic matter gradually decreased (*Nelson, Schoenau & Malhi, 2008*). However, soil P is mainly derived from rock weathering and leaching, and its mobility is very low, which caused the vertical variation of P along soil profile was relatively stable (*Wei et al., 2009*).

Soil C:N:P ratios is important indicators of organic matter composition, soil quality and nutrient supply capacity (*Bui & Henderson, 2013*). In this study, the soil C:N:P ratios among the three communities was 16.9:1.7:1, 25.0:2.3:1 and 28.6:2.5:1 at the topsoil (0-10 cm), respectively (Table 2), and substantially lower than the average global value (186:13:1) (*Cleveland & Liptzin, 2007*). Since the Loess Plateau has undergone a serious soil erosion prior to recent efforts at vegetation restoration, considerable surface loss of C has resulted in a low C:N:P ratio. In this study, soil C:N ratio across different plant communities and soil depths was approximately 10.8 in the Loess Plateau, which was similar to the average level (11.9) in China

(*Tian et al., 2010*), but lower than the world's average value of 13.33 (*Cleveland & Liptzin, 2007*). Previous study showed that soil C:N ratio is negatively correlated with the decomposition rate of organic matter, and low soil C:N ratio indicates that organic matter is well decomposed (*Zhao et al., 2015; Deng et al., 2016*). The soil C:N ratio in grassland, shrubland and forestland was 10.05, 10.78and 11.65, respectively, implying that organic matter has been completely decomposed. However, in this study, the highest value for soil C:P (28.6) and N:P (2.46) ratios in the 0-10 cm soil depth were lower than the corresponding average values (61 and 5.2) in China. This result is explained that the soil C and N concentrations in this study were lower than those in China, whereas the P concentration is was similar to the average level in China. The soil C:N ratio in each plant community maintained relative stability with increasing of soil depths, which is consistent with previous studies (*Tian et al., 2010*). This may be due to the same change dynamics in C and N. In general, the soil C:P and N:P ratios in each plant community decreased with increasing of soil depths, which may be due to the difference in the source of soil C, N and P. Furthermore, this study showed that soil C:P and N:P ratios in forestland was higher than those in shrubland and grassland in topsoil depth, which may be due to the fact that forest had more above-ground and underground biomass than those of shrubland and grassland (*Qi et al., 2015*).

Relationships between C, N and P concentrations and their characteristics of ecological stoichiometry among leaf, litter and soil

Some previous studies have showed a strong correlation between leaf and soil nutrients (*Parfitt, Yeates & Ross, 2005; Cleveland & Liptzin, 2007; Agren, 2008*), while others found that there was no correlation between N and P concentrations in soil and leaf (*Ladanai, Ågren & Olsson, 2010; Yu et al., 2010*). In this study, no significant correlation was found between soil N concentration with leaf N concentration for three plant community types. One possible reason is that through long-term adaptation to the habitat, the N concentration in plant leaves in this region may be more affected by the attributes of the species than the limitation of soil nutrients. In addition, *Reich & Oleksyn, (2004)* showed that the mineral elements of plants are a combination of climate, soil nutrients and species composition. Other studies have suggested that soil temperature, soil water concentration, microbial activity and other factors have a greater impact on the mineral elements of plants (*Chapin & Pastor, 1995; Güsewell, 2004*). In this study, there was a significant correlation between leaf N and P concentrations and their ratios with litter N and P concentrations and their ratios for three plant communities, indicating that the nutrients in litter were derived from plant leaves. In addition, a strong correlation between litter and soil N for three plant communities was observed. As a considerable portion of N and other nutrients elements in the litter could be released into the soil, such that litter was one of the main sources of soil nutrients (*Agren et al., 2013*). In general, this study showed that there is a close correlation between the concentrations of C, N and P and their ratios in leaf, litter and soil in three plant communities, which confirmed that C, N and P in the ecosystem were transported and transformed among plants, litter and soil (*McGroddy, Daufresne & Heedin, 2004*).

CONCLUSION

This study analyzed C, N and P concentrations and their stoichiometric characteristics in leaf, litter and soil of three dominant plant types (grass (*I. cylindrica* and *A. sacrorum*)), bush (*S. viciifolia* and *H. rhamnoides*) and tree (*Q. liaotungensis* and *B. platyphylla*)) during vegetation restoration on the Loess Plateau of China. The results indicated that plant community type had significant effects on leaf, litter and soil nutrient concentration, and their stoichiometry characteristics. C, N and P concentrations in leaf, litter and soil and their ratios exhibited significant differences in dominant plant communities. The N concentration and N:P ratio in leaf and litter were highest in shrub species; grass species had highest leaf P concentration and forest species litter had highest P concentration. Meanwhile, leaf C, N and P concentrations were higher than those in litter and soil ($P<0.05$). Moreover, forest community type had highest soil nutrient concentrations at all soil layers and their ecological stoichiometries were highest in topsoil ($P<0.05$). In addition, soil C:N:P ratios in all plant communities decreased with the increasing of soil depth. Soil P concentration and N:P ratio had significant positive correlations with litter P concentration and N:P ratio for three plant community types ($P<0.05$), respectively; but there were no significant correlations between soil N, P concentrations and N:P ratio with leaf N and P concentrations and N:P ratio ($P>0.5$), respectively. Based on the theory that leaf N:P ratio indicates nutritional limitation for plant growth, this study suggested that *Q. liaotungensis*, *B. platyphylla* and *H. rhamnoides* species growth was co-limited by both of N and P elements, and *S. viciifolia* species growth was limited by P element and *I. cylindrica* and *A. sacrorum* species growth was limited by N element. These results can provide a scientific basis for the reconstruction of degraded ecosystem on the Loess Plateau of China.

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Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Zongfei Wang conceived and designed the field investigation, analyzed the data, wrote drafts of the paper and approved the final draft.
- Fenli Zheng helped with designing fieldwork, contributed to the draft manuscript.

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Table captions

Table 1. Characteristics of three plant types.

Table 2. Nutrient concentrations and characteristics of ecological stoichiometry in leaf at the three plant types.

Table 3. Nutrient concentrations and characteristics of ecological stoichiometry in litter at the three plant types.

Table 4. Profile distribution of soil nutrient concentrations and characteristics of ecological stoichiometry at different community types.

Table 5. Correlations among ecological stoichiometry in leaf, litter and soil at 0-10, 0-20 and 0-100 cm soil depth.

Figure captions

Fig. 1. Concentrations of soil C, N, P and their ecological stoichiometry in the different sampling soil layers at the different plant species.

Fig. 2. Relationships between leaf and litter C: N: P stoichiometric characteristics

Fig. 3. Relationships between leaf and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

Fig. 4. Relationships between litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

Fig. 5. Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for grass community

Fig. 6. Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for shrub community

Fig. 7. Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for forest community.

Figure 1

Concentrations of soil C, N, P and their ecological stoichiometry in thedifferent sampling soil layers at the different plant species

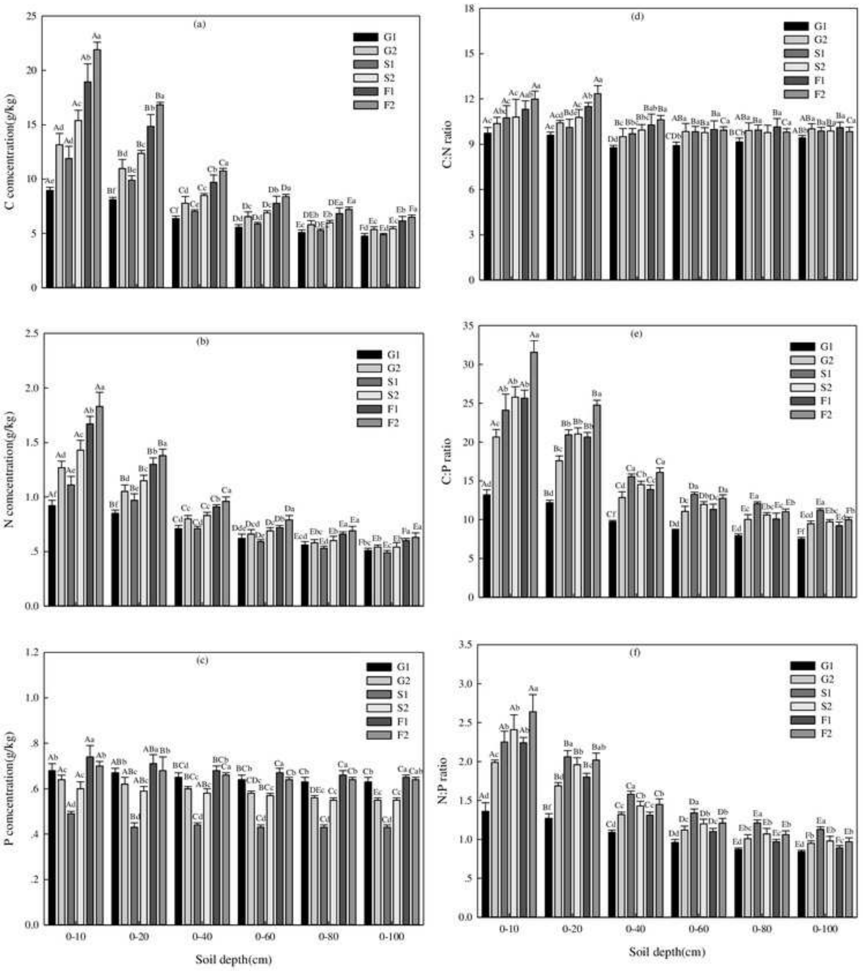

Fig. 1 Concentrations of soil C, N, P and their ecological stoichiometry in the different sampling soil layers at the different plant species. Bars indicates the standard errors (n=6). The lowercase letters above the bars indicate significant differences in different plant species at the same soil layers, and the capital letters represent significant differences in different soil layers at the same plant species ($P< 0.05$). G1 and G2 represent *I. cylindrica* and *A. sacrorum*, respectively; S1 and S2 represent *H. rhamnoides* and *S. viciifolia*, respectively; F1 and F2 represent *B. platyphylla* and *Q. liaotungensis*, respectively.

Figure 2

Relationships between leaf and litter C: N: P stoichiometric characteristics

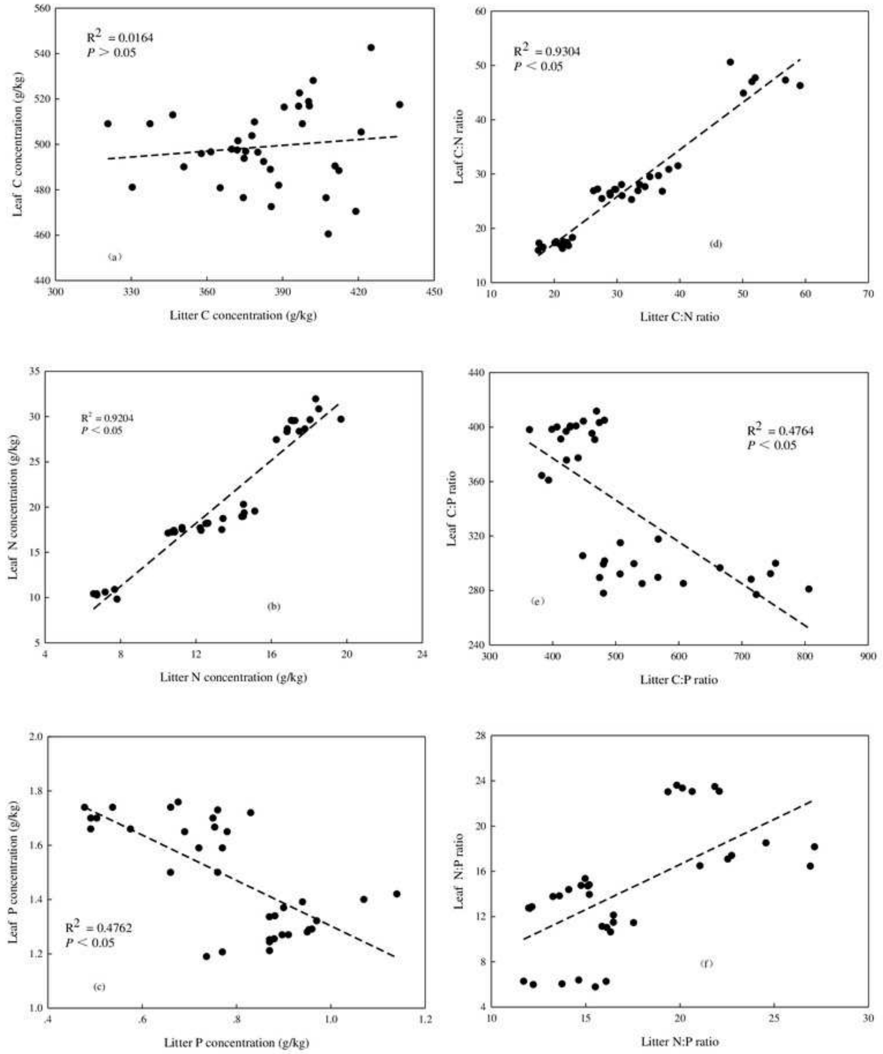

Fig. 2 Relationships between leaf and litter C: N: P stoichiometric characteristics

Figure 3

Relationships between litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

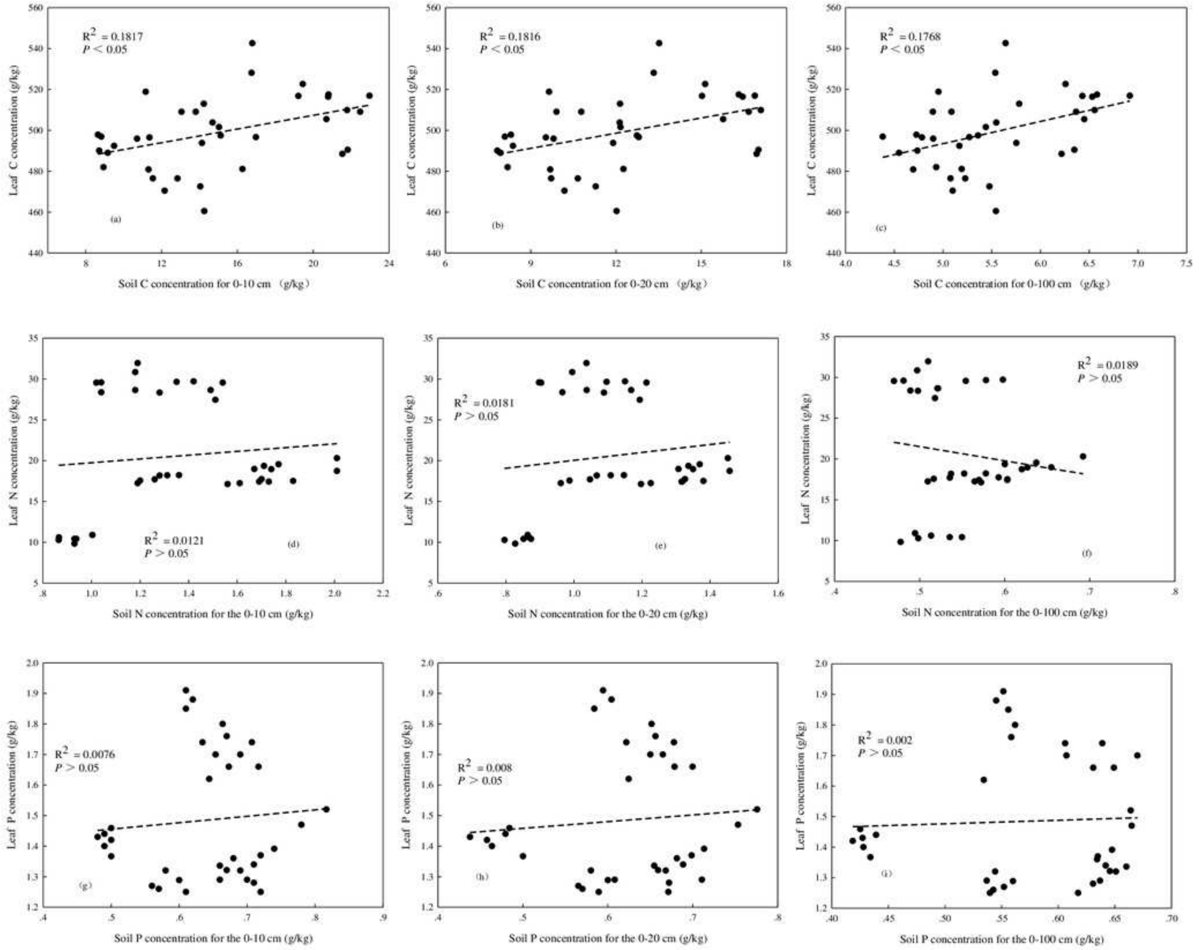

Fig. 3 Relationships between leaf and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

Figure 4

Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cmsoil depths for grass community

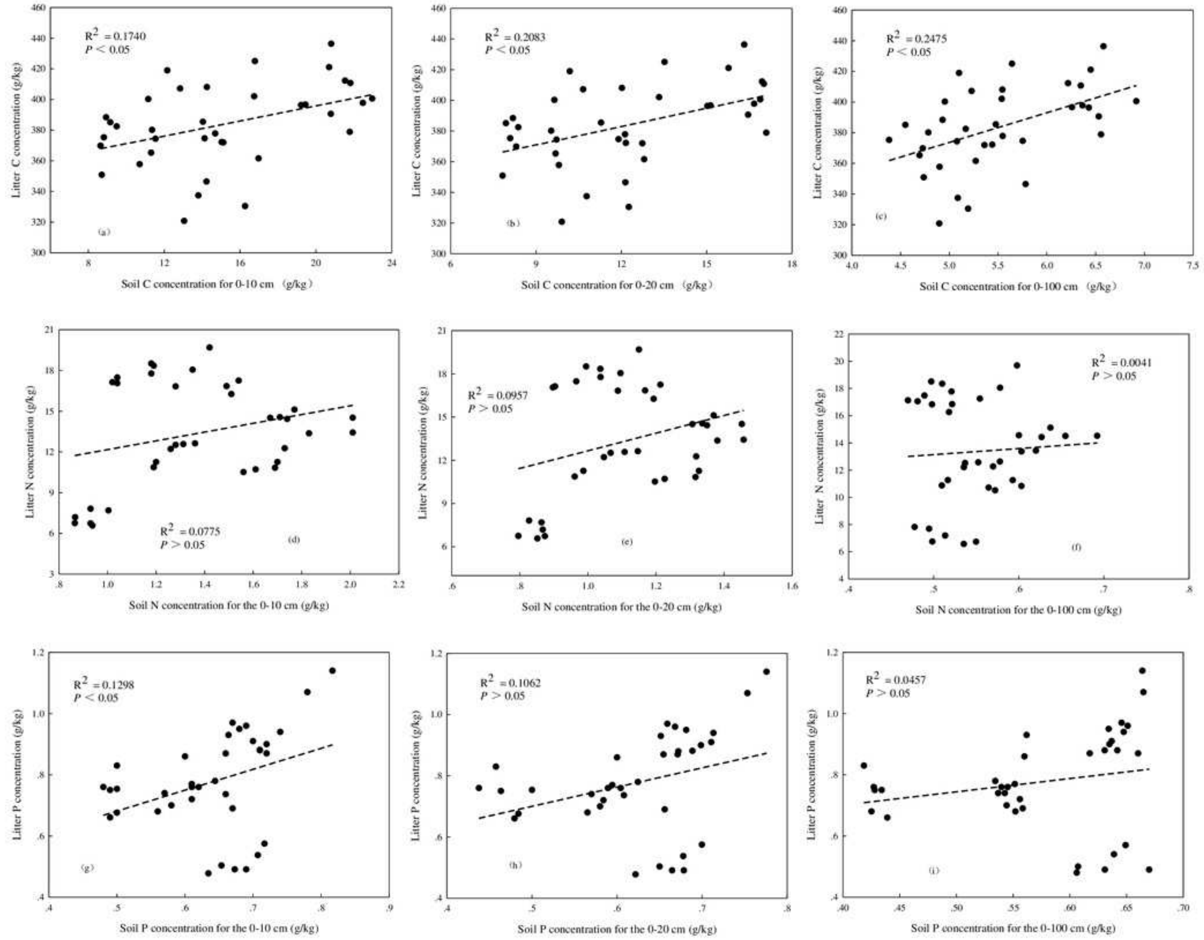

Fig. 4 Relationships between litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

Figure 5

Relationships between leaf and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths

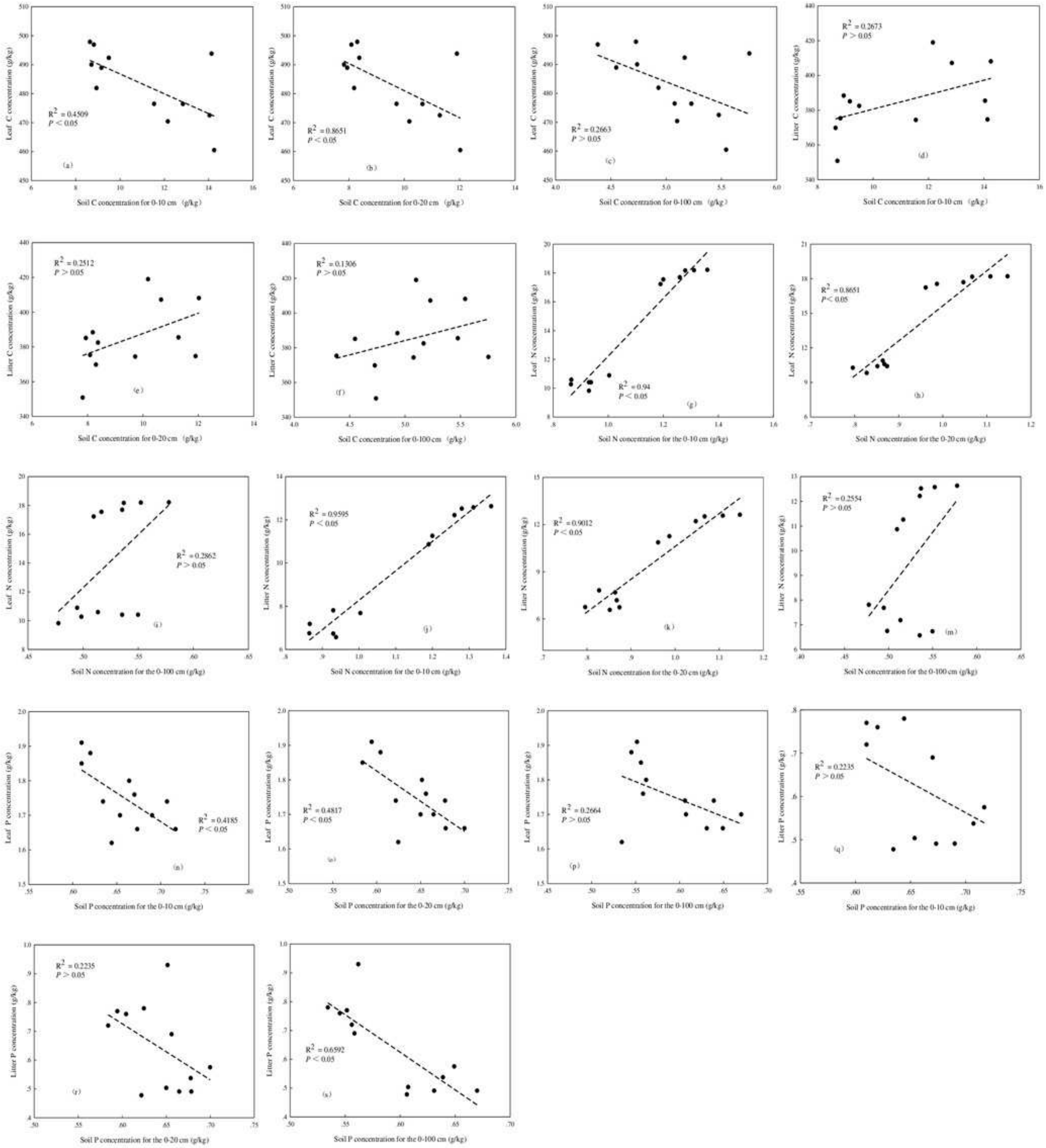

Fig. 5 Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for grass community

Figure 6

Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cmsoil depths for shrub community

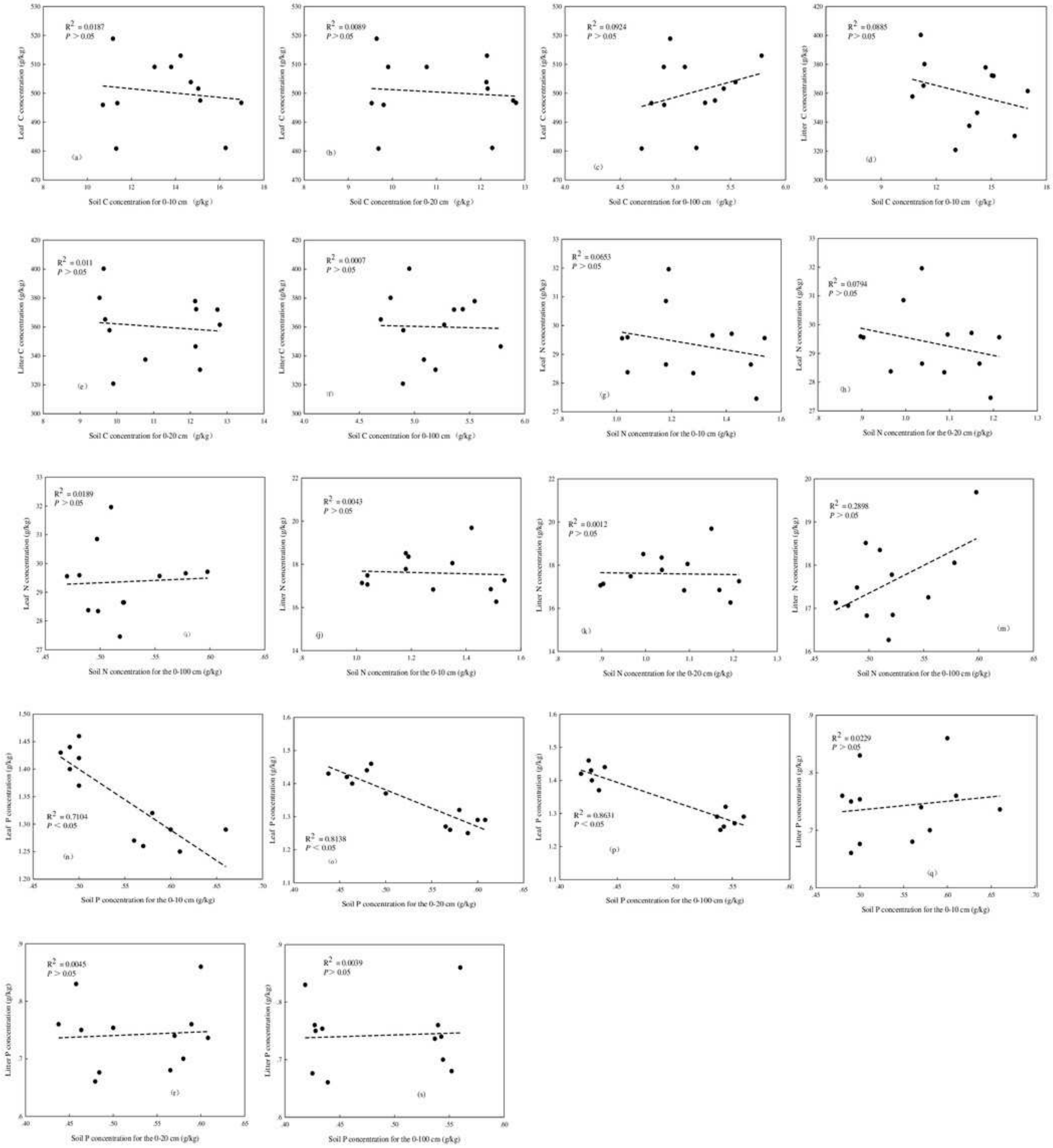

Fig. 6 Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for shrub community

Figure 7

Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cmsoil depths for forest community

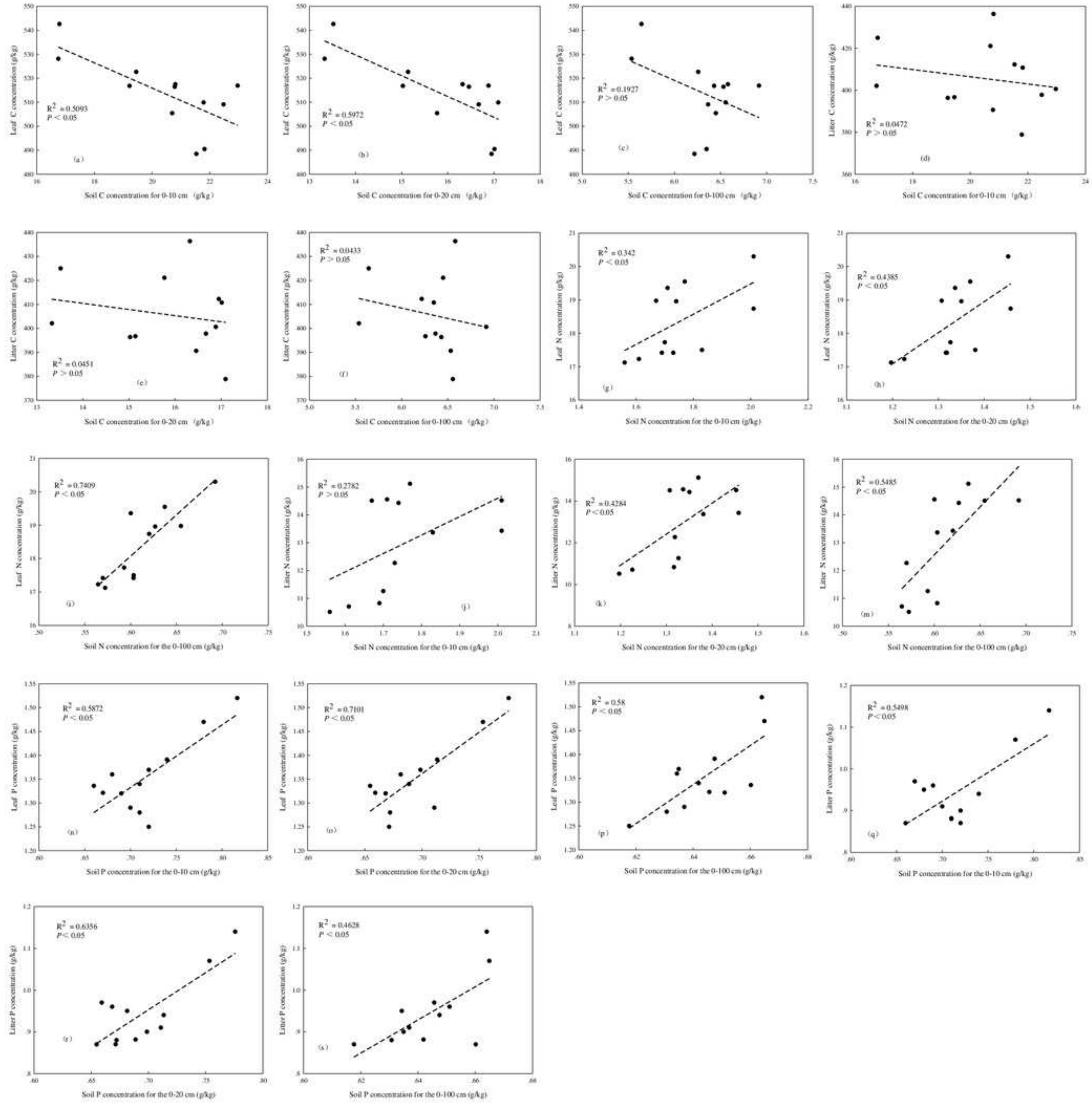

Fig. 7 Relationships between leaf and litter and soil C, N and P concentrations at the 0-10, 0-20 and 0-100 cm soil depths for forest community

Table 1(on next page)

Characteristics of three plant types

Table 1 Characteristics of three plant types.

Vegetation types	Dominant plant species	Abbreviation	Accompanying plant species	Altitude (m)	Coverage (%)	Slope degree (º)	Slope aspect
Forest	*Quercus liaotungensis*	*Q. liaotungensis*	*Carex lanceolata*	1355	60	25	WS260º
	Betula platyphylla	*B. platyphylla*		1133	80	17-20	WS120º
Shrub	*Sophora viciifolia*	*S. viciifolia*	*Stipa bungeana*	1280	55	15-20	WS255º
	Hippophae rhamnoides	*H. rhamnoides*	*Buddleja alternifolia*	1332	75	15-17	WS45º
Grass	*Imperata cylindrica*	*I. cylindrica*	*Artemisia giraldii*	1310	70	10-12	WS259º
	Artemisia sacrorum	*A. sacrorum*	*Themeda japonica*	1336	75	15-20	WS220º

Table 2(on next page)

Nutrient concentrations and characteristics of ecological stoichiometry in leaf at the three plant types

Table 2 Nutrient concentrations and characteristics of ecological stoichiometry in leaf at the three plant types.

Vegetation types	Plant species	C /(g/kg)	N /(g/kg)	P /(g/kg)	C:N	C:P	N:P
Forest	*Q. liaotungensis*	505.20±11.54Bb	18.65±0.98Ab	1.30±0.03Bc	27.14±0.86Ac	387.66±6.67Aa	14.30±0.55Ac
	B. platyphylla	522.20±11.43Aa	18.07±1.00Ab	1.40±0.03Ab	29.01±2.04Ab	372.96±24.02Ab	12.86±0.15Bd
Shrub	*S. viciifolia*	498.95±9.62Ab	28.90±0.83Aa	1.28±0.03Bc	17.27±0.23Ad	390.03±10.76Aa	22.59±0.82Aa
	H. rhamnoides	501.73±12.24Ab	29.83±1.24Aa	1.42±0.03Aa	16.85±0.77Ad	353.70±12.28Bb	21.01±0.97Ba
Grass	*I. cylindrica*	491.35±5.33Ab	10.40±0.32Bc	1.70±0.03Aa	47.30±1.73Aa	289.18±8.13Ac	6.12±0.21Bf
	A. sacrorum	475.02±9.97Bc	17.85±0.38Ab	1.80±0.10Aa	26.63±0.78Bc	264.15±11.98Ac	9.93±0.71Ae

Note: Bars indicate the standard errors (n=6). The lowercase letters above the bars indicate significant differences in leaf at different plant types and the capital letters represent significant differences in leaf at the same plant types of different species ($P < 0.05$).

Table 3(on next page)

Nutrient concentrations and characteristics of ecological stoichiometry in litter at the three plant types

Table 3 Nutrient concentrations and characteristics of ecological stoichiometry in litter at the three plant types.

Vegetation types	Plant Species	C /(g/kg)	N /(g/kg)	P /(g/kg)	C:N	C:P	N:P
Forest	*Q. liaotungensis*	398.48±11.50Aab	13.76±0.82Ab	0.92±0.04Aa	29.12±2.53Bc	432.74±29.10Ad	14.89±0.38Ac
	B. platyphylla	412.93±15.37Aa	12.16±1.91Ac	0.97±0.10Aa	34.59±4.26Ab	430.53±35.34Ad	12.52±0.66Bd
Shrub	*S. viciifolia*	360.08±16.70Ac	17.49±1.12Aa	0.75±0.06Ab	20.66±1.48Ad	486.23±51.01Ac	23.51±1.52Aa
	H. rhamnoides	360.26±26.18Ac	17.72±0.56Aa	0.74±0.06Ab	20.39±2.00Ad	488.92±29.24Abc	24.16±2.27Aa
Grass	*I. cylindrica*	375.32±12.58Abc	7.12±0.48Bd	0.51±0.03Bc	52.93±3.84Aa	734.59±42.66Aa	13.98±1.61Bc
	A. sacrorum	394.81±17.43Aab	12.01±0.69Ac	0.73±0.04Ab	32.98±2.43Bb	542.95±42.20Bb	16.46±0.53Ab

Note: Bars indicate the standard errors (n=6). The lowercase letters above the bars indicate significant differences in litter at different plant types and the capital letters represent significant differences in litter at the same plant types of different species ($P < 0.05$).

Table 4(on next page)

Profile distribution of soil nutrient concentrations and characteristics of ecological stoichiometry at different community types

Table. 4 Profile distribution of soil nutrient concentrations and characteristics of ecological stoichiometry at different community types.

Vegetation Community	Soil layer (cm)	C/(g/kg)	N/(g/kg)	P/(g/kg)	C:N	C:P	N:P
Q. liaotungensis	0-10	21.90±0.69Aa	1.83±0.13Aa	0.70±0.02Ab	11.99±0.53Aa	31.54±1.49Aa	2.64±0.22Aa
	10-20	12.57±0.59Ba	0.99±0.02Ba	0.66±0.03Bab	12.65±0.56Aa	19.05±1.48Ba	1.50±0.06Bb
	20-40	5.51±0.41Ca	0.61±0.06Ca	0.64±0.02BCa	9.13±0.6Ca	8.65±0.69Cb	0.91±0.09Cb
	40-60	4.25±0.24Dab	0.49±0.04Da	0.62±0.02Cb	8.72±0.32Cc	6.88±0.27Dcd	0.79±0.06Dab
	60-80	4.04±0.25 Dab	0.43±0.03Da	0.63±0.02Ca	9.49±0.29BCa	6.40±0.32Dbc	0.67±0.03DEbc
	80-100	3.94±0.25 Da	0.40±0.06Da	0.63±0.02Ca	9.55±0.91Ba	6.28±0.18Dbc	0.64±0.07Ebc
B. platyphylla	0-10	18.95±1.65Ab	1.67±0.70Ab	0.74±0.05Aa	11.31±0.57Aab	25.65±1.04Ab	2.27±0.07Ab
	10-20	11.27±0.65Bb	0.97±0.06Ba	0.69±0.03ABa	11.68±0.31Ab	16.24±0.42Bb	1.39±0.05Bc
	20-40	5.46±0.41Ca	0.59±0.04Ca	0.66±0.03BCa	9.28±1.28Ca	8.32±0.64Cb	0.91±0.07Cb
	40-60	4.48±0.53CDa	0.47±0.05Dab	0.65±0.03BCa	9.45±0.57Cabc	6.95±0.95Dabc	0.74±0.09Dc
	60-80	4.22±0.22Da	0.40±0.03Eab	0.64±0.06BCa	10.62±1.03ABa	6.71±1.02Dbc	0.63±0.07Ebc
	80-100	3.69±0.32Dab	0.37±0.03Eab	0.62±0.05Ca	9.93±0.94BCa	5.98±0.76Dbc	0.61±0.08Ec
S. viciifolia	0-10	15.39±0.94Ac	1.43±0.0.9Ac	0.60±0.03Ac	10.81±1.17Ab	25.81±1.32Ab	2.41±0.19Ab
	10-20	9.58±0.69Bc	0.89±0.02Bb	0.58±0.01Ac	10.76±0.92ABc	16.65±0.96Bb	1.55±0.05Bb
	20-40	5.27±0.41Cab	0.57±0.03Ca	0.58±0.03Ab	9.26±0.35Ca	9.13±0.39Cb	0.99±0.04Cb
	40-60	3.98±0.38Dc	0.43±0.08Dabc	0.54±0.00Bc	9.48±1.16BCabc	7.38±0.70Dbc	0.80±0.15Dab
	60-80	3.52±0.29Dc	0.37±0.06Deb	0.52±0.00Bb	9.79±1.08ABCa	6.76±0.38Dbc	0.70±0.11Db
	80-100	3.40±0.20Dc	0.33±0.03Ec	0.52±0.01Bb	10.25±0.51ABCa	6.55±0.49Db	0.64±0.05Dbc
H. rhamnoides	0-10	11.90±1.12Ad	1.11±0.08Ae	0.49±0.01Ad	10.75±0.81Ab	24.10±2.07Ab	2.25±0.14Ab
	10-20	8.11±0.56Bd	0.85±0.05Bb	0.45±0.03Bd	9.55±0.82ABd	18.12±1.94Ba	1.90±0.16Ba
	20-40	4.45±0.19Cc	0.48±0.01Cb	0.42±0.0.01Cc	9.31±0.39Ba	10.74±0.67Ca	1.15±0.05Ca
	40-60	3.80±0.27CDc	0.38±0.03Dc	0.42±0.01Cd	10.10±1.08abAB	9.08±0.66CDa	0.91±0.08Da
	60-80	3.61±0.08Dc	0.35±0.03Db	0.42±0.01Cc	10.30±1.06ABa	8.61±0.64Da	0.84±0.08Da
	80-100	3.40±0.22Dc	0.36±0.04Dab	0.43±0.02Cc	9.56±1.04ABa	8.01±0.29Da	0.85±0.09Da
I. cylindrica	0-10	13.16±1.05Ad	1.27±0.06Ad	0.64±0.02Ac	10.38±0.43Abc	20.70±1.01Ac	1.99±0.03Ac
	10-20	8.93±0.72Bc	0.86±0.07Bb	0.60±0.03Bc	10.45±0.26Ac	14.78±0.47Bc	1.42±0.05Bc
	20-40	5.03±0.53Cab	0.58±0.01Ca	0.58±0.02Bb	8.72±0.90Bab	8.69±1.02Cb	1.00±0.05Cb
	40-60	4.20±0.27CDab	0.41±0.06Db	0.54±0.01Cc	10.50±1.23Aa	7.74±0.56CDb	0.75±0.10Dc
	60-80	3.70±0.37Dbc	0.37±0.03Dbc	0.52±0.02CDb	10.06±1.01Aa	7.09±0.61Db	0.71±0.07Db
	80-100	3.68±0.42Dab	0.36±0.05Dab	0.50±0.01Db	10.44±1.41Aa	7.34±0.76Da	0.72±0.10Db
A. sacrorum	0-10	8.96±0.29Ae	0.92±0.02Af	0.68±0.03Ab	9.74±0.38ABc	13.24±0.67Ad	1.36±0.11Ad
	10-20	7.31±0.28Bd	0.78±0.05Bc	0.65±0.03Bb	9.46±0.40Bd	11.23±0.34Bd	1.19±0.05Bd
	20-40	4.74±0.37Cbc	0.59±0.06Ca	0.64±0.02BCa	8.02±0.31Cb	7.45±0.43Cc	0.93±0.07Cb
	40-60	4.06±0.19Dab	0.45±0.04Dabc	0.62±0.01CDab	9.17±0.48Bbc	6.52±0.19Dd	0..71±0.06Dc
	60-80	3.60±0.36Ec	0.37±0.02Eb	0.61±0.02CDa	9.88±1.32ABa	5.90±0.46Ec	0.60±04Ec
	80-100	3.49±0.27Ec	0.34±0.03Ec	0.61±0. 02Da	10.43±0.54Aa	5.76±0.33Ec	0.55±0.03Ec

Note: Bars indicates the standard errors (n=6). The lowercase letters above the bars indicate significant differences in different plant species at the same soil layers, and the capital letters represent significant differences in different soil layers at the same plant species ($P < 0.05$).

Table 5(on next page)

Correlations among ecological stoichiometry in leaf, litter and soil at 0-10, 0-20 and 0-100 cm soil depth

Table 5 Correlations among ecological stoichiometry in leaf, litter and soil at 0-10, 0-20 and 0-100 cm soil depth.

Nutrient ratio	Soil depth (cm)								
	0-10			0-20			0-100		
	Soil C: N	Soil C: P	Soil N: P	Soil C: N	Soil C: P	Soil N: P	Soil C: N	Soil C: P	Soil N: P
Leaf C: N	-0.344*	-0.667**	-0.737**	-0.254	-0.732**	-0.880**	-0.381*	-0.880*	-0.813**
Leaf C: P	0.508**	0.693**	0.646**	0.672**	0.640**	0.466**	0.135	0.133	-0.016
Leaf N: P	0.329	0.643**	0.706**	0.261	0.678**	0.792**	0.214	0.676**	0.632**
Litter C: N	-0.395*	-0.708**	-0.758**	-0.303	-0.762**	-0.886**	-0.305	-0.874**	-0.809*
Litter C: P	-0.661**	-0.839**	-0.786**	-0.670**	-0.839**	-0.759**	-0.562**	-0.712**	-0.502**
Litter N: P	-0.092	0.183	0.313	-0.273	0.258	0.542**	-0.108	0.591**	0.721**

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).