Postprint: Stoichiometric Characteristics of N and P in Leaves, Litter, and Soil of Three Main Tree Species in Shaanxi Province

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Abstract

Taking Robinia pseudoacacia, Quercus wutaishanica, and Pinus tabuliformis forests at 39 sampling sites across 29 counties (cities) in Shaanxi Province as the research object, this study analyzed and compared the N and P stoichiometric characteristics of tree leaves, litter, and soil among different tree species, as well as the similarities and differences in their relationships with environmental factors such as latitude, longitude, altitude, mean annual temperature, and annual precipitation, and the potential relationships among the three components, aiming to provide a theoretical basis for understanding the nutrient limitation status of major forest tree species in Shaanxi Province and for formulating reasonable vegetation management and restoration measures. The results showed that leaf N and P contents and their ratios among the three tree species followed the order Robinia pseudoacacia > Quercus wutaishanica > Pinus tabuliformis. Compared with leaves, the variation amplitude of N and P contents in litter was smaller, with the order Robinia pseudoacacia > Quercus wutaishanica > Pinus tabuliformis, while the N:P ratio followed the order Pinus tabuliformis > Quercus wutaishanica > Robinia pseudoacacia. Compared with the 0-10 cm soil layer, N and P contents and N:P ratios in the 10-20 cm layer showed significant decreases across the three tree species ($P < 0.05$), except for P content in Quercus wutaishanica, which showed no significant difference. Leaf N and P contents of Robinia pseudoacacia, Quercus wutaishanica, and Pinus tabuliformis showed no significant correlation with soil N and P contents; however, when considering the three species as a whole, leaf P content was significantly positively correlated with soil P content ($P< 0.05$). Leaf N and P contents generally exhibited increasing trends with increasing mean annual temperature and annual precipitation, and decreasing trends with increasing latitude and longitude, with this pattern being most evident in Robinia pseudoacacia leaves. Litter N content increased with increasing mean annual temperature and annual precipitation, and decreased with increasing latitude and longitude; P content decreased with

increasing annual precipitation and longitude; N:P ratio increased with increasing mean annual temperature and annual precipitation, and decreased with increasing latitude. Within the study area, soil N and P contents increased with increasing latitude and altitude, and with decreasing mean annual temperature, annual precipitation, and longitude, while the N:P ratio showed the opposite trend. Among soil N and P contents and N:P ratios of the three tree species, P content was more strongly influenced by environmental factors than N content, and the relationships between N and P contents and N:P ratios and various environmental factors were generally consistent between the 0-10 cm and 10-20 cm soil layers.

Full Text

Preamble

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N and P Stoichiometric Characteristics of Leaves, Litter, and Soil for Three Dominant Tree Species in Shaanxi Province

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Abstract

This study investigated nitrogen (N) and phosphorus (P) stoichiometry in leaves, litter, and soil associated with three dominant tree species—*Robinia pseudoacacia*, *Quercus liaotungensis*, and *Pinus tabuliformis*—at 39 sites across 29 county-level cities in Shaanxi Province. We aimed to distinguish differences in leaf, litter, and soil N and P stoichiometry among species and their relationships with environmental factors including latitude, longitude, mean annual temperature, and precipitation. Compared with leaves, the range and quantity of litter N and P concentrations decreased significantly across all three species ($P < 0.05$), while the N:P ratio showed species-specific patterns. No significant correlations were found between leaf N (or P) and soil N (or P) for *Quercus liaotungensis* and *Pinus tabuliformis*, indicating their growth was not limited by N or P. However, significant positive correlations between leaf P and soil P across all

species ($P < 0.05$) suggested P limitation in Shaanxi' s forest ecosystems. Leaf N and P increased with mean annual temperature and precipitation, particularly for *Robinia pseudoacacia*. The leaf N:P ratio was negatively correlated with latitude and precipitation but positively correlated with temperature. Litter and soil stoichiometry also showed distinct relationships with environmental gradients. These findings provide a theoretical basis for understanding nutrient limitation status and developing rational vegetation management and restoration strategies for major forest species in Shaanxi Province.

Keywords: *Robinia pseudoacacia*; *Quercus liaotungensis*; *Pinus tabuliformis*; soil; stoichiometric characteristics; geographical factors; climatic factors

Introduction

Ecological stoichiometry studies the balance of multiple chemical elements in ecological processes, unifying research findings across different organizational levels from molecules to ecosystems through elemental ratios. Nitrogen and phosphorus are the primary limiting resources for plant growth in terrestrial ecosystems, playing crucial roles in plant development. The N:P ratio can reflect plant growth rate and serve as an indicator of nutrient limitation on productivity. At broad scales, leaf N and P content increase significantly with increasing latitude and decreasing temperature, while the N:P ratio shows the opposite trend. However, relationships between leaf stoichiometry and environmental factors remain unclear at regional scales, particularly in the Loess Plateau region where studies show no clear correlation between leaf N:P and latitude, temperature, or precipitation.

Litter nutrient content directly affects nutrient return quality and rate, influencing root absorption, soil nutrient content, water-holding capacity, and soil heat capacity. Soil, as the product of biological-environmental interactions, critically affects plant community composition, physiological vigor, and ecosystem structure, function, and productivity. While research on leaf-environment relationships has progressed, studies on litter and soil stoichiometry relative to environmental factors remain limited. Previous work in China has focused primarily on regional and ecosystem scales, with few studies comparing stoichiometric characteristics and their relationships with environmental factors across different tree species within the same region.

According to national forest inventory data, Shaanxi' s forest coverage reaches 43.06%, concentrated in the Qinling, Qiaoshan, and Huanglong Mountains, with natural secondary forests dominating. Major dominant species include *Quercus* spp., *Pinus tabuliformis*, *Pinus sylvestris*, *Platycladus orientalis*, and *Robinia pseudoacacia*. This study selected three widely distributed, area- and volume-weighted species—*Robinia pseudoacacia*, *Quercus liaotungensis*, and *Pinus tabuliformis*—to analyze and compare differences in leaf, litter, and soil stoichiometry, their relationships with environmental factors (latitude, longitude, temperature,

precipitation), and potential interactions among these components. The objective is to provide theoretical support for understanding nutrient limitation and guiding vegetation management and restoration in Shaanxi' s forests.

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1. Study Area

This study was conducted across Shaanxi Province (106°44 26 -110°59 9 E, 33°12 15 -37°45 9 N), covering counties from south to north including Mianxian, Suide, and Mizhi. The province exhibits a semi-arid monsoon climate in the north and northwest, and a warm temperate semi-humid monsoon climate in the central-southern region. Terrain slopes from high northwest to low southeast, with elevations ranging 1900 m. Mean annual precipitation is 450–850 mm, concentrated in summer. Mean annual temperature ranges 8–14°C, decreasing from southeast to northwest. Dominant soil types include black loam and loessal soils.

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2. Field Sampling and Analysis

2.1 Sampling Design

Field surveys were conducted in July–August 2013. At each of the 39 sites, we established 20 m × 50 m plots, recording latitude, longitude, elevation, slope, and aspect. Each plot contained mixed-age stands (young, middle-aged, near-mature, mature, and over-mature trees) with consistent distribution patterns. In each plot, three healthy trees of different diameter classes were selected. Mature leaves were collected from lower canopy branches in four cardinal directions, mixed, and subsampled (~300 g). Litter was collected from five 1 m × 1 m quadrats, mixed, and subsampled (~300 g). Soils were sampled using a soil auger along plot diagonals at 0–10 cm and 10–20 cm depths, then mixed by layer.

2.2 Laboratory Analysis

Plant samples were oven-dried at 65°C to constant weight, ground, and digested with H_2SO_4-H_2O_2. Soil samples were air-dried and sieved. Nitrogen concentration was determined by the Kjeldahl method; phosphorus was measured using the molybdenum-antimony spectrophotometric method after $HClO_4$ digestion.

2.3 Meteorological Data

Mean annual temperature and precipitation data were obtained from the nearest meteorological stations to each sampling site.

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3. Data Analysis

N and P concentrations and N:P ratios were $\log_{10}$-transformed to improve normality and facilitate graphing. One-way ANOVA was used to compare differences among species for leaf, litter, and soil stoichiometry. When variances were homogeneous, Tukey' s test was used for multiple comparisons; when non-homogeneous, Tamhane' s T2 test was applied. Pearson correlation analysis examined relationships among leaves, litter, soil layers, and environmental factors. All analyses were performed in SPSS Statistics 19.0. Data are presented as means ± standard deviation. Coefficient of variation (CV) was calculated as: CV = (standard deviation / mean) × 100%.

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4. Results

4.1 Stoichiometric Characteristics of Leaves, Litter, and Soil

Leaves: N and P concentrations differed significantly among species ($P < 0.05$), following the order *Robinia* > *Quercus* > *Pinus*. N:P ratios were also species-dependent. Leaf N and P were strongly positively correlated ($P < 0.01$), indicating consistent proportional relationships during leaf construction.

Litter: Compared with leaves, litter N and P concentrations decreased significantly ($P < 0.05$), though the interspecific ranking remained *Robinia* > *Quercus* > *Pinus*. The N:P ratio increased significantly for *Robinia* and *Quercus* but not for *Pinus*.

Soil: Soil N and P concentrations also varied significantly by species and depth ($P < 0.05$). In the 0–10 cm layer, N and P concentrations were highest in *Quercus* stands, while N:P ratios were highest in *Pinus* stands. Concentrations decreased significantly in the 10–20 cm layer for all species ($P < 0.05$), except for *Quercus* P, which showed no significant depth difference.

and present detailed statistical characteristics of leaf, litter, and soil stoichiometry.

4.2 Correlations Among Leaves, Litter, and Soil

Correlation analysis revealed significant positive relationships between leaf and litter N and P for *Robinia* and *Pinus* ($P < 0.05$), indicating litter nutrients were derived from leaves. However, correlations between leaf nutrients and soil nutrients were generally weak. Only *Robinia* leaf P correlated significantly with soil P ($P < 0.05$). Litter N and P correlated significantly with soil N and P across all species ($P < 0.05$), demonstrating litter as a primary soil nutrient source.

shows Pearson correlation coefficients among components.

4.3 Relationships with Environmental Factors

Leaves: Across all species, leaf N and P increased with mean annual temperature and precipitation ($P < 0.05$), especially in *Robinia*. Leaf N:P ratio decreased with latitude and precipitation but increased with temperature. *Robinia* showed the strongest environmental relationships, while *Quercus* showed the weakest.

Litter: Litter N increased with temperature and precipitation but decreased with latitude and longitude ($P < 0.05$). Litter P decreased with precipitation and longitude. The litter N:P ratio increased with temperature and precipitation but decreased with latitude.

Soil: Soil N and P increased with latitude and altitude but decreased with temperature, precipitation, and longitude ($P < 0.05$). The soil N:P ratio showed opposite trends. Soil P was more strongly correlated with environmental factors than soil N. Relationships were consistent between 0–10 cm and 10–20 cm layers.

[Figure 2: see original paper], [Figure 3: see original paper], and [Figure 4: see original paper] illustrate relationships between stoichiometry and geographic/climatic factors. , , and present correlation coefficients.

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5. Discussion

5.1 Stoichiometric Patterns and Nutrient Limitation

Mean leaf N (18.13 mg/g) and P (1.27 mg/g) in this study were lower than global averages but consistent with other Loess Plateau research. The mean N:P ratio (14.26) was also lower than global values, suggesting potential N limitation. However, the lack of correlation between leaf and soil N for *Quercus* and *Pinus* suggests these species are not strongly N-limited. The significant leaf-soil P correlation indicates P limitation across Shaanxi' s forests, consistent with regional soil P deficiency.

The consistent ranking of species' nutrient concentrations (*Robinia* > *Quercus* > *Pinus*) reflects inherent species traits. *Robinia*, a nitrogen-fixing legume, maintained highest N concentrations. *Pinus*, with conservative nutrient strategies, showed lowest concentrations. The lower variability in N:P ratios compared to individual N and P concentrations indicates strong stoichiometric homeostasis.

5.2 Nutrient Resorption and Litter-Soil Linkages

Significant decreases in N and P from leaves to litter demonstrate nutrient resorption—the withdrawal of nutrients from senescing tissues. This adaptation increases nutrient retention time and reduces dependency on soil uptake. The strong correlations between litter and soil nutrients confirm litter decomposition

as a primary pathway for nutrient return to soil, maintaining ecosystem N:P cycling.

5.3 Environmental Controls and Regional Variation

The positive relationship between leaf N/P and temperature/precipitation aligns with global patterns of increased nutrient availability in warmer, wetter conditions. However, the negative relationship with latitude contrasts with some global studies, highlighting the importance of regional context. *Robinia*' s broad ecological niche and strong environmental responses suggest high plasticity, while *Quercus*' s weak environmental correlations indicate strong stoichiometric homeostasis and resistance to disturbance.

Soil stoichiometry showed clearer environmental relationships than leaves, particularly for P, reflecting stronger direct control by climate and geography on soil processes. The consistent patterns between soil layers suggest vertical homogeneity in environmental responses.

5.4 Implications for Forest Management

These results indicate that P is the primary limiting nutrient in Shaanxi' s forests. Management practices should focus on P conservation and supplementation. Species-specific strategies are needed: *Robinia* plantations may enhance soil N through fixation but require P management; *Pinus* forests show conservative nutrient cycling suitable for harsh sites; *Quercus* forests demonstrate stable stoichiometry, making them resilient to environmental change. The strong environmental relationships, particularly for soil nutrients, suggest that climate change will alter nutrient cycling, requiring adaptive management.

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Note: Figure translations are in progress. See original paper for figures.