Postprint: Ecological Stoichiometric Characteristics of Robinia pseudoacacia and Pinus tabuliformis Plantation Ecosystems in the Loess Hilly Region

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Abstract

To elucidate the differences in ecological stoichiometric characteristics among different plantation ecosystems, this study employed a combination of field sampling and laboratory analysis to investigate the C, N, and P stoichiometric characteristics of arbor, shrub and herb, litter, and soil (soil depth 0-100 cm) in Robinia pseudoacacia (deciduous broad-leaved species) and Pinus tabuliformis (evergreen coniferous species) plantations in the Loess Hilly Region of Northern Shaanxi. The results showed that: 1) The C content in various organs (leaf, branch, stem, bark, root) of Robinia pseudoacacia arbor was significantly lower than that of Pinus tabuliformis, while its N and P contents were significantly higher. Consequently, the C:N and C:P ratios of Pinus tabuliformis were significantly greater than those of Robinia pseudoacacia, whereas the N:P ratio was lower. 2) The N and P contents in the litter under Robinia pseudoacacia plantation were significantly higher than those under Pinus tabuliformis, but the C content was significantly lower. Additionally, the C:N ratio of litter under Pinus tabuliformis (70.21) was greater than that under Robinia pseudoacacia (19.71), indicating slower decomposition of litter under Pinus tabuliformis and thus favoring nutrient storage. 3) The soil C and N contents in both Robinia pseudoacacia and Pinus tabuliformis plantations decreased with increasing soil depth, while the P content remained essentially unchanged. The soil C content in Robinia pseudoacacia plantation was lower than that in Pinus tabuliformis plantation, with no significant differences in N and P contents between the two. 4) In Robinia pseudoacacia plantation, correlations among C, N, P and their stoichiometric ratios in arbor-shrub-herb leaves, litter, and soil were mainly concentrated in the 10-20 cm and 20-30 cm soil layers, whereas in Pinus tabuliformis plantation, correlations between various components and soil nutrients were relatively weak, with no significant correlations in the 20-30 cm soil layer. This suggests that, compared with Robinia pseudoacacia plantation, the supply of N and P from soil layers in Pinus tabuliformis plantation had no significant effect on leaf N and P contents. This study lays a foundation for in-depth understanding of the nutrient coupling and cycling mechanisms in ecosystems of the Loess Hilly Region, and also provides certain guidance for vegetation restoration efforts in this region.

Full Text

Preamble

Stoichiometric Characteristics of *Robinia pseudoacacia* and *Pinus tabuliformis* Plantation Ecosystems in the Loess Hilly-Gully Region, China

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Abstract

To comprehensively understand the stoichiometric characteristics of different plantation ecosystems, we conducted field investigations and laboratory analyses to study carbon (C), nitrogen (N), and phosphorus (P) stoichiometry in the arbor, shrub, herb, litter, and soil (0–100 cm depth) components of deciduous broad-leaved *Robinia pseudoacacia* and evergreen coniferous *Pinus tabuliformis* plantations in the Loess hilly-gully region of northern Shaanxi, China. The results showed that: (1) The C concentrations of arbor organs were significantly lower in *Robinia* than in *Pinus* plantations, while N and P concentrations were significantly higher. Consequently, C:N and C:P ratios were significantly higher in *Pinus* than in *Robinia* plantations, but the N:P ratio was lower. (2) Litter N and P concentrations were significantly higher in *Robinia* than in *Pinus* plantations, but C concentration was significantly lower. The litter C:N ratio was higher in *Pinus* (70.21) than in *Robinia* (19.71), indicating slower decomposition and favorable nutrient storage in *Pinus* plantations. (3) Soil C and N concentrations decreased with increasing soil depth, while P concentrations remained relatively constant in both plantations. Soil C concentration in *Robinia* was lower than in *Pinus*, but no significant differences were observed in N and P concentrations. (4) Correlations between C, N, P, and their ratios in arbor leaf, shrub leaf, herb leaf, litter, and soil were more concentrated in the 10–20 cm and 20–30 cm soil layers in *Robinia* plantations, whereas these correlations were relatively weaker in *Pinus* plantations, with no significant correlations even in the 20–30 cm layer. This indicated that in *Pinus* plantations, soil N and P supply had no significant impact on leaf N and P content. This study establishes a foundation for illuminating ecosystem nutrient coupling mechanisms and provides guidance for vegetation restoration in the Loess hilly-gully region.

Keywords: stoichiometric characteristics; *Robinia pseudoacacia*; *Pinus tabuliformis*; plantation; C, N, P

Introduction

Ecological stoichiometry integrates fundamental principles of biology, physics, and chemistry to examine the balance of multiple chemical elements in ecological processes. Since Redfield proposed the concept of ecological stoichiometry, research on stoichiometric characteristics has expanded rapidly worldwide. Carbon (C), nitrogen (N), and phosphorus (P) are structural and limiting elements for plant growth and development. Studying the interactions and stoichiometric relationships of C, N, and P in ecosystem plants, particularly different tree species, holds significant scientific importance for understanding nutrient coupling cycling characteristics and mechanisms.

Plantations constitute an important component of global forest resources, playing crucial roles in ecological restoration and economic development, especially in the severely eroded and infertile Loess Plateau hilly region. Like other forest ecosystems, plantation ecosystems have complete composition and structure, with complex ecological processes intertwined. Research on stoichiometric relationships among plantation ecosystems in the Loess hilly-gully region can clarify nutrient cycling processes and is important for plantation planning and soil conservation. Current vegetation restoration efforts on the Loess Plateau have focused primarily on *Robinia pseudoacacia* plantations, particularly regarding water balance and nutrient cycling, with some reports on leaf stoichiometric characteristics. However, few studies have examined nutrient cycling characteristics of different plantation ecosystem types, and differences in ecological stoichiometry among plantation types remain unclear.

Soil serves as both a conduit and major reservoir for energy flow and material cycling in ecosystems, with close structural and functional linkages to vegetation. These relationships may differ among plantation ecosystem types. Previous research on the Loess Plateau has examined how soil nutrient content differences affect vegetation growth and stability, but comprehensive studies remain in early stages. Jiang et al. analyzed C, N, and P stoichiometric characteristics of leaves, litter, and soil for 16 major tree species in Shaanxi Province, but studies exploring relationships between plant and soil stoichiometric characteristics across different plantation ecosystem types are limited. Particularly, vegetation nutrient cycling status and relationships between different components and soil remain unclear. Investigating plant-soil relationships in different plantation types to evaluate differences in ecosystem nutrient cycling and develop reasonable vegetation management measures is an urgent issue in plantation management.

Robinia pseudoacacia and *Pinus tabuliformis* are major afforestation species in the Loess hilly-gully region, with wide distribution, strong soil and water conservation capacity, and important roles in Loess Plateau development and management. Comparative studies of stoichiometric differences between these two plantation ecosystems are representative. This research examines *Robinia* and *Pinus* plantation ecosystems in Yichuan County, northern Shaanxi Loess hilly-gully region, comparing their plant and soil C, N, and P stoichiometric characteristics through field sampling and laboratory experiments. Using stoichiometric principles, we explore nutrient limitation and supply mechanisms for ecosystem structure and productivity maintenance in different plantation ecosystems on the Loess Plateau, examine differences in stoichiometric characteristics and element interactions between the two plantation types, and analyze correlations between plant-soil stoichiometric characteristics and nutrient cycling mechanisms. This study aims to enrich the C, N, and P stoichiometric database for northwestern and national China, providing guidance for vegetation restoration in the Loess hilly-gully region.

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1. Study Area and Plot Setup

The study area is located in Yichuan County, Yan' an City, Shaanxi Province (109.41°–110.32° E, 35.42°–36.23° N). This region belongs to the warm temperate semi-arid zone with distinct continental monsoon climate characteristics, with an average annual temperature of 10.3°C, annual precipitation of 521.1 mm concentrated in summer, frost-free period of 185 days, and forest coverage of 66.37%. The total forest area is 25.5×10 hm^2 with a vegetation coverage of 54.04%. Dominant tree species include *Robinia pseudoacacia*, *Pinus bungeana*, and *Quercus wutaishanica*. Understory shrubs are primarily *Rosa xanthina* and *Cotinus coggygria*, while herbs are dominated by *Carex lanceolata*.

Sampling plots were established in July 2015. Sampling sites were selected in mature *Robinia* plantations (45–49 years) and mature *Pinus* plantations (27–30 years) with similar site conditions, relatively uniform stands, and homogeneous vegetation distribution, typical of the Loess hilly-gully region. In *Robinia* plantations, understory shrubs were dominated by *Rosa xanthina* and herbs by *Carex lanceolata*. In *Pinus* plantations, understory shrubs were dominated by *Cotinus coggygria* and herbs by *Carex lanceolata*. Three 20 m × 20 m plots were established for each species. Within each plot, three 1 m × 1 m litter subplots, three 2 m × 2 m shrub subplots, and three 1 m × 1 m herb subplots were randomly established along the diagonal. Plot surveys recorded altitude, slope aspect, slope position, slope gradient, tree height, DBH, and stand density.

Basic information of sample plots

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2. Sample Collection and Processing

Samples were collected in July 2015. For each plot, three standard trees were selected based on average DBH to collect various organs (leaf, branch, trunk, fine root <2 mm, thick root >2 mm). Leaves were taken from current-year mature foliage. Shrubs and herbs were collected using whole-harvest method, with herbs separated into aboveground and belowground parts. Litter was collected simultaneously. Each sample was collected in triplicate (100 g fresh weight) and transported to the laboratory. Soil samples were collected at 0–10, 10–20, 20–30, 30–50, and 50–100 cm depths using a soil auger in each subplot.

All plant and litter samples were oven-dried at 65°C to constant weight, then ground. Soil samples were air-dried and ground. All samples were sieved through 0.25 mm mesh and stored in sealed bags. Plant and soil C, N, and P concentrations were determined using potassium dichromate-sulfuric acid oxidation method, semi-micro Kjeldahl method, and antimony-potassium tartrate colorimetry, respectively.

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3. Data Processing and Analysis

Data were analyzed using SPSS 19.0 and SigmaPlot 10.0. One-way ANOVA was used to test differences in plant and soil C, N, P contents and stoichiometric characteristics between species, with significance level set at $P = 0.05$. Levene' s test was used for homogeneity of variance. If variances were homogeneous, LSD method was used for multiple comparisons; if not, Tamhane' s T2 method was used. Pearson correlation analysis was used to test relationships between stoichiometric characteristics of plant leaves, litter, and soil. Data are presented as mean ± SE.

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2. Results

2.1 Tree Layer Organs C, N, P Contents and Stoichiometric Ratios

In *Robinia*, C, N, and P contents were highest in bark (444.64 g/kg), leaf (39.40 g/kg), and leaf (2.03 g/kg), respectively. In *Pinus*, C, N, and P contents were highest in branch (512.76 g/kg), leaf (14.64 g/kg), and leaf (0.83 g/kg), respectively. Except for leaf N content, all other organ C, N, and P contents were significantly higher in *Robinia* than in *Pinus.* C:N, C:P, and N:P ratios showed significant differences between species, with *Pinus* values significantly greater than *Robinia* for most organs.

C, N, P contents and stoichiometric ratios of arbor organs in *Robinia* and *Pinus* plantations (mean±SE)

2.2 Understory Plants and Litter C, N, P Contents and Stoichiometric Ratios

Shrub leaf and branch C contents showed no significant difference between plantations, while N and P contents were significantly greater in *Robinia* than in *Pinus*. Shrub C:P and N:P ratios were significantly smaller in *Robinia* than in *Pinus*. Herb leaf and root C contents showed no significant difference between plantations, while N and P contents were significantly smaller in *Robinia* than in *Pinus*. Herb C:N and C:P ratios were significantly smaller in *Robinia* than in *Pinus*, but N:P ratio showed no significant difference.

Litter C content was significantly smaller in *Robinia* than in *Pinus*, while N and P contents were significantly greater. Litter C:N and C:P ratios were significantly smaller in *Robinia* than in *Pinus*, but N:P ratio was significantly greater.

C, N, P contents and stoichiometric ratios of understory plants and litter in *Robinia* and *Pinus* plantations (mean±SE)

2.3 Soil Layer C, N, P Contents and Stoichiometric Ratios

Soil C and N contents decreased with increasing soil depth, while P content remained relatively constant in both plantations. *Pinus* plantations had higher C and N contents than *Robinia* across all soil layers, with significant differences in the 10–20 cm layer for C and in the 0–10 cm and 10–20 cm layers for N. No significant differences in P content were observed between plantations across all layers.

C:N, C:P, and N:P ratios showed decreasing trends with soil depth. *Robinia* soil C:N ratio was significantly smaller than *Pinus* in all layers. *Robinia* soil C:P ratio was significantly smaller than *Pinus* in the 0–10 cm layer, with no significant differences in other layers.

[Figure 1: see original paper] Soil C, N, P contents and stoichiometric ratios in *Robinia* and *Pinus* plantations

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3. Discussion

3.1 Tree Layer C, N, P Content and Stoichiometric Ratio Characteristics

C, N, and P are essential nutrients for plant growth and development, constituting the primary elements of plant dry matter. *Robinia* arbor organs had significantly lower C content than *Pinus*, with leaf C content (426.23 g/kg) lower than global average leaf C content (464 g/kg) and Shangguan' s study on Loess Plateau vegetation (438 g/kg), but higher than Zheng' s study (505.30 g/kg). Higher organic compound content in plant material indicates higher C content. Therefore, *Robinia* leaves contained lower organic compounds than *Pinus* leaves, consistent with global research showing higher organic compound content in coniferous than broad-leaved species.

As important nutrient organs, leaves had significantly higher N and P contents than other arbor components. *Robinia* leaf N content (39.40 g/kg) was higher than global plant leaf N content (20.09 g/kg, 20.62 g/kg) and Chinese plant leaf N content studied by Reich and Oleksyn (16.20 g/kg), while *Pinus* leaf N content (10.53 g/kg) was lower. As a legume, *Robinia* has strong nitrogen fixation capacity, while native coniferous *Pinus* has weaker nitrogen fixation. *Robinia* leaf P content (2.03 g/kg) was higher than Chinese plant leaf P content studied by Han et al. (1.60 g/kg) and Loess Plateau vegetation studied by Jiang et al. (1.56 g/kg), while *Pinus* leaf P content (0.83 g/kg) was lower. Under high N conditions, *Robinia*' s nitrogen fixation capacity may be enhanced, promoting P absorption and utilization, leading to higher P content in all organs.

C:N:P stoichiometry is an important physiological indicator reflecting plant growth rate. Generally, lower C:N and C:P ratios indicate faster growth rates. In this study, *Robinia* leaf C:N and C:P ratios were significantly lower than *Pinus*, suggesting higher growth rates in *Robinia* plantations. Plant growth is co-limited by N and P when N:P < 14, primarily P-limited when N:P > 16, and co-limited when $14 <$ N:P < 16. *Robinia* leaf N:P ratio (19.47) indicated P limitation, while *Pinus* leaf N:P ratio (12.67) indicated N limitation.

Litter C:N ratio is an important factor affecting decomposition rate and nutrient return. Lower C:N ratio facilitates decomposition, while higher C:N ratio hinders it. *Pinus* litter C:N ratio (70.21) was significantly higher than *Robinia* (19.71), indicating slower decomposition and better nutrient storage in *Pinus* plantations. In the Loess Plateau region, *Pinus* litter can reduce water and soil erosion, making it an excellent species for soil and water conservation.

3.2 Soil Layer C, N, P Content and Stoichiometric Ratio Characteristics

Due to soil adsorption of P, severe surface erosion, and intense weathering in the Loess Plateau, soil P content was significantly lower than the global average, consistent with patterns of low P content in Chinese soils. Soil C and N contents decreased with depth while P remained constant, related to differences in nutrient sources. C and N primarily originate from organic matter formed by litter and root decomposition, which are mainly distributed in surface soil. P is derived from rock weathering and leaching, with atmospheric deposition also contributing. As a sedimentary mineral element, P migrates relatively little in soil, distributing uniformly throughout soil profiles.

Pinus plantations had higher soil C content than *Robinia*, possibly due to slower litter decomposition and greater soil organic matter accumulation in *Pinus* plantations. Soil C:P ratio can indicate nutrient limitation status. *Robinia* soil C:P ratio was significantly smaller than *Pinus* in the 0–10 cm layer, suggesting higher P availability in *Robinia* soils. However, soil N:P ratios showed no significant differences between plantations, and the applicability of N:P ratio thresholds requires further investigation.

3.3 Relationships Between Tree/Shrub/Grass Leaves, Litter, and Soil Layer C, N, P Contents and Stoichiometric Ratios

Significant relationships exist among the stoichiometric characteristics of plant leaves, litter, and soil. Plants absorb nutrients from soil through roots and return them as plant residues, demonstrating that C, N, and P cycling occurs through transport and transformation among multiple pools. Previous studies have shown close correlations between plant and soil N and P contents.

This study found different relationships between nutrient characteristics of different plant layers and soil. In *Robinia* plantations, correlations were concentrated in 10–20 cm and 20–30 cm soil layers, while *Pinus* plantations showed weaker correlations, with no significant correlations in the 20–30 cm layer. This indicates that in *Pinus* plantations, soil N and P supply had no significant impact on leaf N and P content. Plant root distribution characteristics may explain these differences. *Robinia* roots >2 mm diameter are mainly distributed in 0–10 cm soil, with fewer roots in 10–30 cm, resulting in weaker nutrient cycling between plants and soil in surface layers. As an evergreen conifer, *Pinus* has different litter decomposition capacity and root distribution characteristics, leading to weaker correlations between plant/litter and soil nutrients. Correlations may also be related to soil environment and human disturbance levels.

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4. Conclusion

Significant differences in C, N, and P stoichiometric characteristics exist between *Robinia* and *Pinus* plantation ecosystems in Yichuan County, northern Shaanxi Loess hilly-gully region. *Robinia* arbor organs had significantly lower C content but significantly higher N and P content than *Pinus*. Lower C:N and C:P ratios in *Robinia* components indicate higher growth rates compared to *Pinus*. *Pinus* litter had significantly higher C:N ratio than *Robinia*, indicating slower decomposition and better nutrient storage. Soil C and N contents decreased with depth while P remained constant. *Pinus* soil C content was higher than *Robinia*, but N and P contents showed no significant differences.

Correlation analysis revealed different relationships between plant and soil nutrient characteristics across ecosystem layers. *Robinia* showed more concentrated correlations in 10–20 cm and 20–30 cm soil layers, while *Pinus* showed weaker correlations. This indicates that soil N and P supply had no significant impact on leaf N and P content in *Pinus* plantations. This study enriches the C, N, P stoichiometric database for northwestern and national China and establishes a foundation for understanding ecosystem nutrient coupling mechanisms in the Loess hilly-gully region.

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