

Soil Carbon and Nitrogen Characteristics Under Two Understory Vegetation Types in *Pinus massoniana* Forest and Their Relationship with Litter Quality: Postprint

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Abstract

Taking aerial seeding *Pinus massoniana* plantations as the research object, through typical sample plot investigation and sample measurement, paired samples t-test and redundancy analysis (RDA) methods were used to analyze the soil carbon and nitrogen characteristics of two understory vegetation types (Dicranopteris-type and grass-type) and their relationship with litter quality. The results showed that: (1) The contents of soil organic carbon, microbial biomass carbon, dissolved organic carbon, total nitrogen, available nitrogen, microbial biomass nitrogen, and dissolved organic nitrogen in the 0-10 cm and 10-20 cm soil layers were all significantly higher in the grass-type than in the Dicranopteris-type ($P < 0.05$), while in the 20-40 cm and 40-80 cm soil layers, the carbon and nitrogen indices of the two vegetation types did not show the same variation pattern, and the differences were not significant ($P > 0.05$). (2) For both vegetation types, the C content and C/N ratio of the semi-decomposed and undecomposed litter layers were significantly higher in the Dicranopteris-type than in the grass-type ($P < 0.05$), while the N content was significantly higher in the grass-type than in the Dicranopteris-type ($P < 0.05$); for the same vegetation type, the C content and C/N ratio of the undecomposed layer were significantly greater than those of the semi-decomposed layer, while the N content was significantly greater in the semi-decomposed layer than in the undecomposed layer ($P < 0.05$). (3) In the 0-10 cm soil layer, the C/N ratios and C contents of both litter types were significantly negatively correlated with all soil carbon and nitrogen indices ($P < 0.05$), while the correlations between N content and soil carbon and nitrogen indices were not significant ($P > 0.05$); in the 10-20 cm soil layer, the C/N ratio of the semi-decomposed layer of Dicranopteris-type showed significant correlations with all soil carbon

and nitrogen indices ($P < 0.05$), and the C content of grass-type litter also showed significant correlations with all soil carbon and nitrogen indices ($P < 0.01$). The lower the C/N ratio of understory vegetation litter, the faster its decomposition rate, which is conducive to soil nutrient accumulation; the lower C/N ratio of grass-type litter compared to *Dicranopteris*-type is an important reason for its higher soil carbon and nitrogen indices.

Full Text

Preamble

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Characteristics of Soil Carbon and Nitrogen and Their Relationship with Litter Quality Under Different Understory Vegetation in *Pinus massoniana* Plantations

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Abstract

This study investigated aerially seeded *Pinus massoniana* plantations to analyze soil carbon and nitrogen distribution characteristics and their relationships with litter quality under two understory vegetation types: *Dicranopteris* (fern) and graminoid (grass). Using paired sample t-tests and redundancy analysis (RDA), we examined these relationships across multiple soil depths. The results showed that: (1) At soil depths of 0-10 cm and 10-20 cm, soil organic carbon, microbial biomass carbon, dissolved organic carbon, total nitrogen, available nitrogen, microbial biomass nitrogen, and dissolved organic nitrogen were all significantly higher under graminoid vegetation than under *Dicranopteris* ($p < 0.05$). However, at depths of 10-20 cm and 20-40 cm, the patterns between the two vegetation types differed but were not statistically significant ($p > 0.05$). (2) The C content and C/N ratio of both semi-decomposed and undecomposed litter layers were significantly higher for *Dicranopteris* than for graminoid vegetation ($p < 0.05$), while the N content of graminoid litter was significantly higher than that of *Dicranopteris* ($p < 0.05$). (3) At 0-10 cm, the litter C/N ratio and C content were significantly negatively correlated with soil carbon and nitrogen indicators ($p < 0.05$), while N content showed no significant correlation ($p > 0.05$). At 10-20 cm, the semi-decomposed litter C/N ratio of *Dicranopteris* was significantly correlated with soil carbon and nitrogen ($p < 0.05$), and the litter C content

of graminoid was significantly correlated with soil carbon and nitrogen ($p < 0.01$). The lower litter C/N ratio of graminoid vegetation was associated with faster decomposition rates, which facilitated soil nutrient accumulation. This explains why soil carbon and nitrogen indicators were significantly higher under graminoid than under *Dicranopteris* vegetation.

Keywords: *Pinus massoniana*; aerially seeded plantation; understory vegetation; soil carbon and nitrogen; litter quality

Introduction

Soil nitrogen content and its dynamic equilibrium directly influence soil fertility and forest productivity. Soil microbial biomass carbon and nitrogen represent active components of soil organic matter, playing crucial roles in soil nutrient transformation and carbon-nitrogen cycling, and serving as important indicators of soil carbon pool dynamics. Dissolved organic carbon and nitrogen, as labile fractions of organic matter, are more responsive to land use patterns, forest management practices, and habitat disturbances, making them valuable indicators of soil quality changes.

Understory vegetation and litter significantly impact soil carbon and nitrogen nutrients. As an essential component of forest ecosystems, understory vegetation maintains biodiversity, ecosystem stability, and sustained site productivity. It primarily influences soil carbon-nitrogen cycling through root exudates and litter inputs. Litter serves as a critical link for material and energy exchange between vegetation and soil, representing an important source of soil carbon input and playing a vital role in maintaining forest soil fertility and nutrient balance. Through microbial decomposition, litter releases plant nutrients back into the soil, thereby affecting soil carbon-nitrogen nutrient pools.

Current research on understory vegetation and litter effects on soil carbon and nitrogen has focused primarily on understory removal and manipulation of litter quantity and composition. However, few studies have examined how different understory vegetation types affect soil carbon and nitrogen through litter quality. Research on *Pinus massoniana* forests has concentrated on understory vegetation characteristics, biomass, diversity, and relationships between coverage and environmental factors or soil quality, with limited investigation into the relationship between understory litter and soil properties. While some studies have explored relationships between soil organic carbon and litter quality in planted *P. massoniana* forests and the effects of litter decomposition on soil carbon pools, research on the relationship between litter quality and soil carbon-nitrogen characteristics under different understory vegetation types in these forests remains lacking. Such studies could provide insights into the interaction mechanisms between understory vegetation and soil.

Ganzhou City in Jiangxi Province was once a region with severe soil erosion,

particularly in Xingguo County where erosion was widespread. Since the 1980s, large-scale aerial seeding of *P. massoniana* has been conducted to control soil erosion and restore forest vegetation, achieving significant success. During understory vegetation recovery, two main types have emerged: *Dicranopteris* and graminoid. However, differences in soil carbon-nitrogen content and litter quality between these two types remain unclear. This study, conducted in Xingguo County—a representative area of aerially seeded *P. massoniana* forests in southern Jiangxi—analyzes the distribution characteristics of soil carbon and nitrogen and their relationship with litter quality under these two understory vegetation types. The findings provide a scientific basis for understanding the mechanisms of understory vegetation effects on soil carbon and nitrogen in degraded red soil regions and offer guidance for scientific management and ecological restoration of aerially seeded *P. massoniana* forests.

1. Study Area Overview

Xingguo County is located in the southern part of central subtropical China, in central-southern Jiangxi Province and northern Ganzhou City, with geographic coordinates of 115°01' -115°51' E, 26°03' -26°42' N. The region has a warm and humid central subtropical climate with an average annual temperature of 18.9°C and average annual precipitation of 1,539 mm, concentrated in the growing season. The frost-free period lasts 280–300 days. Soil types are primarily red soil developed from granite parent material and Quaternary red clay. The county is rich in forest resources, with main vegetation types including evergreen broadleaf forest and *Cunninghamia lanceolata* plantations.

According to statistics from the Xingguo County Forestry Bureau, extensive aerial seeding of *P. massoniana* began in the 1980s, primarily on granite hills with severely degraded original vegetation. The current preserved aerial-seeded forests are mainly middle-aged stands from the 1980s.

2. Methods

2.1 Sample Plot Setup

Field surveys of the main distribution areas of aerially seeded *P. massoniana* forests revealed relatively simple understory vegetation. Shady slopes and lower slope positions were dominated by *Dicranopteris*, while sunny slopes primarily supported both *Dicranopteris* and graminoid vegetation. *Dicranopteris* vegetation consisted exclusively of *Dicranopteris dichotoma* as the dominant species, while graminoid vegetation was dominated by *Paspalum thunbergii*, *Agropyron cristatum*, and *Arundinella hirta*, with small amounts of *Loropetalum chinense* and *Lespedeza bicolor*. Upper slope positions typically had sparse understory vegetation with minimal shrub development.

This study established paired typical sample plots (20 m × 20 m) in pure aeri-ally seeded *P. massoniana* forests with low human disturbance. Plots were set up as one-to-one pairs for *Dicranopteris* and graminoid understory types, with horizontal distances between paired plots not exceeding 300 m. Stand age was controlled at 30 years, all plots were on sunny mid-slope positions with granite-developed red soil, and understory coverage ranged from 60% to 80%. [Figure 1: see original paper] shows the distribution of sample plots.

2.2 Soil Sampling and Analysis

Soil samples were collected using soil augers at upper, middle, and lower positions within each plot. Soil layers were divided into 0-10, 10-20, 20-40, and 40-80 cm depths. Soil microbial biomass carbon and nitrogen, available nitrogen, and dissolved organic carbon and nitrogen were measured from fresh soil samples. Samples from each plot were mixed, and approximately 500 g of mixed soil was divided into two portions: one stored at low temperature for analysis of microbial biomass carbon/nitrogen and dissolved organic carbon/nitrogen, and the other air-dried for determination of soil organic carbon and total nitrogen.

Soil indicators were measured using standard methods: soil organic carbon by potassium dichromate oxidation, total nitrogen by Kjeldahl method, available nitrogen by alkaline hydrolysis diffusion, dissolved organic carbon and nitrogen by 0.5 M K₂SO₄ extraction, microbial biomass carbon and nitrogen by chloroform fumigation-extraction, and dissolved organic nitrogen as the difference between total soluble nitrogen and inorganic nitrogen measured using a flow analyzer.

2.3 Litter Sampling and Analysis

Representative 1 m × 1 m litter quadrats were established at upper, middle, and lower positions in each plot. Litter was collected by separating semi-decomposed (mostly fragmented debris) and undecomposed (intact leaves showing no decomposition signs) layers. Samples were oven-dried to constant weight, then ground and analyzed for carbon and nitrogen content. Carbon content was determined by potassium dichromate oxidation with external heating, and nitrogen content by sulfuric acid digestion followed by Kjeldahl determination.

2.4 Data Processing and Analysis

Differences in soil carbon-nitrogen and litter indicators between the two understory vegetation types were analyzed using paired sample *t*-tests in SPSS 19.0. Redundancy analysis (RDA) in Canoco 4.5 was used to examine correlations between litter and soil carbon-nitrogen indicators. Data processing and table preparation were performed in Microsoft Excel.

3. Results

3.1 Soil Carbon and Nitrogen Characteristics Under Different Understory Vegetation Types

Paired sample t-tests of soil carbon and nitrogen indicators across soil layers revealed that at 0–10 cm and 10–20 cm depths, all soil carbon and nitrogen indicators were significantly higher under graminoid vegetation than under *Dicranopteris* ($p < 0.05$). Specifically, graminoid vegetation had 2.13, 1.19, 1.08, 1.14, 2.01, 2.10, and 1.52 times higher organic carbon, microbial biomass carbon, dissolved organic carbon, total nitrogen, available nitrogen, microbial biomass nitrogen, and dissolved organic nitrogen, respectively, compared to *Dicranopteris*.

At 10–20 cm depth, the same pattern persisted with graminoid $>$ *Dicranopteris*, though the magnitude of difference was much smaller than in the 0–10 cm layer. At 20–40 cm and 40–80 cm depths, no consistent patterns emerged between the two vegetation types, and differences were not significant ($p > 0.05$).

The differences in soil carbon and nitrogen indicators between the two understory vegetation types were primarily manifested in the 0–10 cm and 10–20 cm layers, likely due to the shallow root distribution of both *Dicranopteris* and graminoid vegetation, which had limited influence on deeper soil layers.

3.2 Litter Quality Under Different Understory Vegetation Types

Litter nutrient contents for the two understory vegetation types are shown in Table 2. *Dicranopteris* litter had C/N ratios of 37.09–44.13, C content of 377.66–402.31 g/kg, and N content of 9.14–10.21 g/kg. Graminoid litter had C/N ratios of 32.76–38.18, C content of 369.06–390.62 g/kg, and N content of 10.29–11.33 g/kg.

For both vegetation types, the C content and C/N ratio were significantly higher in the undecomposed layer than in the semi-decomposed layer ($p < 0.05$), while N content showed the opposite pattern ($p < 0.05$). The C/N ratio and C content of *Dicranopteris* litter were significantly higher than those of graminoid litter ($p < 0.05$), whereas the average N content of graminoid litter was significantly higher than that of *Dicranopteris* ($p < 0.05$).

shows the detailed C, N contents and C/N ratios of litter under the two understory vegetation types.

3.3 Relationships Between Soil Carbon-Nitrogen and Litter Quality

Redundancy analysis results for the relationships between soil carbon-nitrogen and litter indicators are shown in [Figure 2: see original paper], [Figure 3: see original paper], and [Figure 4: see original paper]. At 0–10 cm depth, the first and second axes of the RDA for *Dicranopteris* explained 80.3% and 11.1% of soil carbon-nitrogen variation, respectively. The correlation between litter indicators and soil carbon-nitrogen, from strongest to weakest, was: semi-decomposed

layer C/N > semi-decomposed layer C content > undecomposed layer C/N > undecomposed layer C content. For graminoid vegetation, the first and second axes explained 80.6% and 5.6% of variation, respectively. The semi-decomposed layer C/N and undecomposed layer C content showed extremely significant negative correlations with soil carbon-nitrogen indicators ($p < 0.01$), while other indicators were not significantly correlated.

At 10-20 cm depth, the semi-decomposed layer C/N of both vegetation types was significantly correlated with soil carbon-nitrogen indicators ($p < 0.05$). For *Dicranopteris*, the first and second axes explained 36.0% and 30.8% of variation, respectively, while for graminoid vegetation they explained 36.8% and 31.4%. The litter C content of graminoid vegetation was extremely significantly correlated with soil carbon-nitrogen ($p < 0.01$), while other indicators showed no significant correlations ($p > 0.05$).

4. Discussion

4.1 Litter Quality Characteristics Under Different Understory Vegetation Types

This study demonstrated that *Dicranopteris* litter had significantly higher C/N ratios and C content but lower N content compared to graminoid litter ($p < 0.05$). These differences likely stem from distinct biological characteristics of the vegetation types, resulting in different intensities and transfer rates of nutrient absorption. The C/N ratio was consistently higher in the undecomposed layer than in the semi-decomposed layer for both vegetation types, while N content showed the opposite pattern ($p < 0.05$). These findings align with previous research on *P. massoniana* plantations showing higher N content in semi-decomposed litter. The primary reason may be that during early decomposition, water-soluble carbohydrates and lipids are rapidly lost, causing carbon content to decrease and relative nitrogen content to increase as mass loss rates exceed nutrient release rates.

4.2 Soil Carbon and Nitrogen Characteristics Under Different Understory Vegetation Types

Different understory vegetation types input varying quantities and qualities of organic matter through litter decomposition, which differentially affects soil microorganisms and carbon-nitrogen characteristics. This study found that soil carbon and nitrogen indicators at 0-10 cm and 10-20 cm depths were significantly higher under graminoid vegetation than under *Dicranopteris*, consistent with findings from similar studies. For example, research on grassland soils showed that graminoid species had higher nitrogen cycling rates and availability than aster species. Studies in southern rare earth mining areas also found higher rhizosphere soil total nitrogen and organic carbon under planted grasses compared to naturally recovered *Dicranopteris*.

The higher soil carbon and nitrogen under graminoid vegetation can be attributed to two main factors. First, the significantly lower litter C/N ratio of graminoid vegetation enhances microbial activity, accelerating decomposition and nutrient return to the soil. Second, graminoid species have fibrous root systems that may form associative symbioses with nitrogen-fixing bacteria, whereas *Dicranopteris* has rhizome-based root systems, creating different rhizosphere effects on soil carbon and nitrogen.

4.3 Correlations Between Soil Carbon-Nitrogen and Litter Quality

Numerous studies have shown that litter is a crucial source of soil nutrients in forest ecosystems, and its elemental composition and decomposition rate significantly influence soil nutrient content. This study found that for both vegetation types, the semi-decomposed layer C/N ratio and undecomposed layer C content were extremely significantly negatively correlated with soil carbon-nitrogen indicators at 0–10 cm depth ($p < 0.01$), and significantly negatively correlated at 10–20 cm depth ($p < 0.05$). These results are consistent with studies showing that litter C/N ratios are significantly negatively correlated with soil organic carbon and organic matter.

The mechanism appears to be that lower litter C/N ratios enhance microbial activity, accelerating decomposition and mineralization rates, thereby increasing soil carbon-nitrogen nutrient content. Research on Chinese forest ecosystems has demonstrated that litter decomposition rates decrease as C/N ratios increase, slowing nutrient return to soil. Higher C/N ratios indicate greater content of recalcitrant compounds like lignin and cellulose, which reduce decomposition rates. The influence of litter quality on soil nutrients is primarily manifested in the surface soil layer, with effects diminishing with depth, as nutrients from decomposing litter first enter the topsoil.

5. Conclusion

Aerially seeded *Pinus massoniana* forests were established in severely degraded areas with extensive soil erosion. The severe erosion prior to seeding caused loss of soil seed banks, with graminoid species comprising a large proportion of the remaining seeds, facilitating the development of graminoid-dominated understory vegetation. *Dicranopteris*, as a pioneer herb in southern China's eroded areas, can rapidly cover the ground surface once its spores colonize an area, inhibiting recovery of other plants including graminoids and forming *Dicranopteris*-dominated understory communities.

This study revealed that soil organic carbon, microbial biomass carbon, dissolved organic carbon, total nitrogen, available nitrogen, microbial biomass nitrogen, and dissolved organic nitrogen at 0–10 cm and 10–20 cm depths were all significantly higher under graminoid vegetation than under *Dicranopteris* ($p < 0.05$). The litter C/N ratio and C content of *Dicranopteris* were significantly

higher than those of graminoid vegetation, while graminoid litter N content was significantly higher ($p < 0.05$). Comprehensive analysis indicates that graminoid vegetation is superior to *Dicranopteris* in improving soil quality. For aerially seeded *P. massoniana* forests where *Dicranopteris* is the dominant understory species, appropriate artificial measures should be taken to control *Dicranopteris* propagation and promote recovery of graminoid and other plants, which would enhance soil quality in these forests.

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