Root Biomass and Carbon Storage Characteristics of Chinese Fir and Masson Pine Plantations at Different Stand Ages in Guangxi (Postprint)

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Abstract

To understand the characteristics of belowground root biomass and carbon storage in Chinese fir (Cunninghamia lanceolata) and Masson pine (Pinus massoniana) plantations at different stand ages, this study examined plantations across five age stages (young, middle-aged, near-mature, mature, and over-mature) in the main production regions of Guangxi. Using whole-root excavation and soil coring methods, we obtained biomass data for standard tree roots, shrub and herb roots, and stand fine roots, and measured their carbon content to analyze the distribution characteristics of belowground root biomass and carbon storage across stand ages. The results showed that total belowground root biomass ranged from 9.06–31.40 Mg/ha for Chinese fir and 7.91–53.40 Mg/ha for Masson pine, with an overall increasing trend across stand age stages. Fine root biomass exhibited a decreasing-then-increasing trend with stand age in Chinese fir plantations, while showing a gradually decreasing trend in Masson pine. Root carbon content across stand layers followed the pattern: arbor > shrub > herb and fine roots. The temporal trends in belowground root carbon storage mirrored those of biomass, with total carbon storage of layer-specific roots and soil fine roots ranging from 7.56–21.97 Mg/ha for Chinese fir and 8.86–29.95 Mg/ha for Masson pine across stand ages. Belowground root carbon storage was predominantly contributed by arbor roots, with their proportional contribution increasing with stand age.

Full Text

Preamble

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Biomass and Carbon Storage in Roots of *Cunninghamia lanceolata* and *Pinus massoniana* Plantations at Different Stand Ages in Guangxi

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Abstract

To understand the characteristics of belowground root biomass and carbon storage in *Cunninghamia lanceolata* and *Pinus massoniana* plantations at different stand ages, this study investigated plantations in the main production areas of Guangxi across five age stages. Standard tree root biomass, shrub-grass root biomass, and stand fine root biomass were obtained using whole-root excavation and soil auger methods, and their carbon contents were measured. Total belowground root biomass ranged from 9.06-31.40 Mg/ha for Chinese fir and 7.91-53.40 Mg/ha for Masson pine, showing an overall increasing trend with stand age. Fine root biomass in Chinese fir plantations initially decreased then increased with age, while that in Masson pine plantations showed a decreasing trend. Root carbon content across stand layers followed the pattern: tree roots > shrub roots > herb roots. Carbon storage trends mirrored biomass trends. Total belowground root carbon storage ranged from 7.56-21.97 Mg/ha for Chinese fir and 8.86-29.95 Mg/ha for Masson pine, with tree roots dominating and their proportion increasing with stand age.

Keywords: carbon storage; roots; stand age; *Cunninghamia lanceolata*; *Pinus massoniana*

Introduction

Roots are critical organs for plant adaptation to terrestrial life and growth, providing mechanical support for aboveground portions while absorbing, transporting nutrients and water. They play vital roles in ecosystem material cycling and energy flow [1-3]. Since the mid-20th century, forest root research has gradually gained attention as roots consume photosynthates through respiration and turnover, and input organic matter into soil, deepening understanding of forest ecosystem functions and effects [4]. Scholars worldwide have conducted extensive research on root ecology, distribution, structure, and physiology [3,5-7]. International studies show root biomass accounts for 20-25% of total biomass, highlighting its importance. However, forest ecosystem carbon storage estimates based on forest inventory data have considerable uncertainty, as they often exclude carbon in understory vegetation, surface litter, roots, and soil components [8-10]. Further in-depth research is needed for accurate carbon accounting.

Cunninghamia lanceolata and *Pinus massoniana* are widely planted in southern China, occupying substantial proportions of forest resources and playing important roles in maintaining ecosystem balance [11-13]. Since the late 20th century, numerous studies have examined plantation biomass and carbon storage under different stand densities, successional stages, and management practices [14-18]. However, research on belowground roots and understory layers has been relatively weak compared to aboveground components due to the difficulty of root excavation. Most forest carbon pool studies have focused primarily on tree layers. This study selected Chinese fir and Masson pine plantations across different age stages in Guangxi' s main production areas to measure standard tree root biomass, shrub-grass root biomass, and stand fine root biomass, aiming to provide scientific basis for forest carbon sink estimation and ecosystem carbon cycle research in China.

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1. Study Area Overview and Methods

1.1 Study Area Overview

The study area is located in Guangxi Zhuang Autonomous Region (104°26 -112°04 E, 20°54 -26°24 N), situated in the western Liangguang Hills facing the Beibu Gulf. The terrain features mountainous highlands and plateaus surrounding central and southern plains, forming a mountainous basin landform. The region has a subtropical monsoon climate with mean annual temperatures of 16.5-23.1°C, extreme maximum temperatures of 33.7-42.5°C, and extreme minimum temperatures of -8.4-2.9°C. Annual precipitation exceeds 1070 mm, with 70-85% concentrated in April-September. Vegetation is diverse and species-rich, belonging to the subtropical evergreen broadleaf forest zone. Guangxi' s forest area reaches 12.525 million hectares with 64.83% forest coverage and 678.34 million m^3 total living stock volume, accounting for 6.41% and 3.42% of national totals respectively. Chinese fir and Masson pine plantations constitute major timber forest types in Guangxi.

1.2 Sample Plot Selection and Establishment

Based on the IPCC Good Practice Guidance for systematic random sampling and distribution characteristics of Chinese fir and Masson pine plantations in Guangxi, sampling points were selected using the 7th forest inventory data and Guangxi timber forest age group classification standards. Five age stages were established for each plantation type: young forest, middle-aged forest, near-mature forest, mature forest, and over-mature forest. Three replicate plots (50 m × 20 m = 1000 m^2) were established for each age stage. All trees with DBH 2 cm were measured for diameter, crown width, and coordinates. Each plot was further divided into subplots for shrub and herb surveys. Stand conditions were consistent across plots. shows age classification, and shows plot distribution and general conditions.

1.3 Tree Layer

Based on inventory data, sample trees representing different ages and DBH classes were selected following the principle of more trees in central diameter classes and fewer in extreme classes. Branches, leaves, flowers, and fruits were weighed separately. For root biomass, whole excavation was performed on sample trees outside plots. Roots were washed, oven-dried at 105°C to constant weight, and the dry/fresh mass ratio was calculated. Polynomial, power, and exponential regression equations were developed between root dry mass and DBH. Using inventory data and regression equations, individual tree root biomass was calculated to obtain total tree layer root biomass.

1.4 Shrub Layer

Within each plot, 2 m × 2 m subplots were established in an "S" pattern. All shrub species were surveyed, and roots were harvested by full excavation, oven-dried, and converted to dry mass to calculate shrub root biomass per unit area.

1.5 Herb Layer

Herbaceous roots were surveyed in 1 m × 1 m subplots using whole excavation, with fresh weight measured and converted to dry mass.

1.6 Fine Roots

Fine roots (2 mm diameter) were sampled using soil augers at the center of subplots. Samples were collected from 0–20 cm and 20–40 cm depth layers, soaked in flowing water, sieved, air-dried, weighed fresh, then oven-dried to constant weight. All plant root samples were crushed and sieved for total carbon analysis using potassium dichromate oxidation. Data processing, multiple comparisons, and regression modeling were performed in Excel 2010 and SPSS 18.0.

2. Results

2.1 Tree Root Biomass Regression Models

Extensive forest biomass studies show correlations between tree organ biomass and dendrometric factors that can be fitted with mathematical models. Common models include power functions with DBH or DBH^{2}×height as variables, polynomial equations, and exponential functions. This study selected the optimal model through analysis. Due to large errors in height measurements, single-variable DBH models were chosen. The selected regression models were:

- Chinese fir: W_R = $0.023D^{2}\cdot$ ($R^{2} = 0.904$)
- Masson pine: W_R = $0.023D^{2}\cdot^{2\ 1}$ ($R^{2} = 0.984$)

Both models showed excellent fit and could effectively predict root biomass for both plantation types .

2.2 Stand-level Root Biomass Allocation

Tree root biomass in Chinese fir plantations ranged from 6.71-30.30 Mg/ha, generally increasing with stand age except for a non-significant decline from middle-aged to near-mature stages. Masson pine tree root biomass ranged from 0.14-51.16 Mg/ha, with significant differences among all age stages except between near-mature and mature forests. Chinese fir biomass exceeded Masson pine at all stages except mature and over-mature forests .

Shrub root biomass varied by stand type and age, being higher in young forests due to abundant light. Chinese fir shrub root biomass was highest in young forest, with only young forest being significantly higher than other stages. Masson pine shrub root biomass exceeded Chinese fir at all ages except over-mature forest. Herb root biomass in Chinese fir showed no clear age trend, peaking in near-mature forest (5.76 Mg/ha), while Masson pine herb root biomass decreased with age. No significant differences were found between plantation types except in near-mature stage.

Total belowground root biomass ranged from 9.06-31.40 Mg/ha for Chinese fir and 7.91-53.40 Mg/ha for Masson pine, showing increasing trends with age. Chinese fir biomass was higher than Masson pine in young (17.13 vs 10.38 Mg/ha) and middle-aged (24.68 vs 11.45 Mg/ha) stages, but lower in near-mature (23.33 vs 28.28 Mg/ha) and over-mature (31.40 vs 53.40 Mg/ha) stages.

2.3 Fine Root Biomass Allocation

Fine root biomass in Chinese fir plantations ranged from 1.04-9.64 Mg/ha across 0-40 cm depth, generally decreasing with stand age. Biomass was higher in 0-20 cm than 20-40 cm layers, except in near-mature and over-mature stages where the pattern reversed. Masson pine fine root biomass ranged from 1.44-12.32 Mg/ha, also decreasing with age and showing higher biomass in surface layers .

2.4 Root Carbon Content

Carbon content varied by layer, stand type, and age. Chinese fir tree root carbon content ranged 352.80-569.18 g/kg, averaging 583.73-514.77 g/kg across ages. Shrub roots averaged 481.31-544.73 g/kg, herb roots 586.81-386.34 g/kg, and fine roots 575.50-434.84 g/kg. Masson pine showed similar patterns with tree roots 552.82-526.99 g/kg, shrub roots 528.14-489.61 g/kg, herb roots 476.92-441.12 g/kg, and fine roots 539.33-433.34 g/kg. Young Chinese fir had higher carbon content than other ages .

2.5 Stand-level Carbon Storage Allocation

Carbon storage trends mirrored biomass patterns. Chinese fir tree layer carbon storage ranged 5.26-17.74 Mg/ha, shrub layer 0.17-1.34 Mg/ha, herb layer 0.07-28.28 Mg/ha, and total root carbon storage 7.56-21.97 Mg/ha. Masson pine tree layer ranged 3.37-29.34 Mg/ha, shrub layer 0.28-2.34 Mg/ha, herb layer 0.87-2.32 Mg/ha, and total 8.86-29.95 Mg/ha .

2.6 Fine Root Carbon Storage Allocation

Fine root carbon storage in 0-40 cm depth ranged 0.23-2.31 Mg/ha for Chinese fir and 0.24-1.93 Mg/ha for Masson pine, decreasing with soil depth. Masson pine fine root carbon storage was 0.61-4.95 Mg/ha, higher than Chinese fir .

2.7 Root Carbon Storage Allocation Proportions

Chinese fir total belowground carbon storage was 7.56-21.97 Mg/ha, increasing with age. Masson pine storage was 8.68-29.95 Mg/ha, generally increasing except for a decline in mature forest. Tree roots dominated carbon storage, accounting for 51.82-78.63% in Chinese fir and 46.94-94.43% in Masson pine, with proportions increasing with age. Shrub roots comprised 0.23-6.58% (Chinese fir) and 0.55-15.40% (Masson pine), while fine roots accounted for 4.25-30.43% and 2.98-26.70% respectively, decreasing with age [Figure 1: see original paper].

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3. Discussion

Forest biomass can be obtained through direct harvesting or indirect modeling. Direct methods are destructive, while indirect methods (biomass models) are primary approaches. Common predictive variables include DBH, height, and density [17,19]. Single-variable DBH models are widely used because height measurements often contain large errors. This study' s power function models based on DBH showed high precision (R^2 = 0.904-0.984) and effectively predicted root biomass for both plantation types.

Forest biomass is closely related to biological and abiotic factors including regional hydrothermal conditions, soil properties, forest type, species composition, and stand density [20-21]. Tree root biomass generally increases rapidly with stand age, with most forest types showing logistic relationships between biomass density and age [20]. This study found that Masson pine tree root biomass and total stand root biomass increased with age, while Chinese fir showed a decline from middle-aged to near-mature stages due to management practices like thinning and pruning. These patterns align with studies on Yunnan pine forests [22].

Root systems decrease substantially with soil depth [23-24]. As depth increases, soil texture becomes denser and nutrient content decreases, causing fine root biomass to concentrate in surface layers for nutrient acquisition while deeper roots primarily absorb water [28]. Both plantation types showed decreasing fine root biomass with depth, consistent with studies on Yunnan pine forests [22], Changbai Mountain forests [27], and northern Michigan hardwood forests [28]. Fine root distribution reflects functional shifts and changes in soil resource availability, primarily influenced by soil physicochemical properties and moisture content [29].

Carbon storage allocation proportions showed tree roots dominated in both plantations (except young Masson pine), increasing with stand age. This pattern aligns with biomass trends. Soil fine roots represent important components of belowground carbon storage, making root carbon storage a non-negligible part of forest ecosystem carbon estimation. Research on belowground processes helps improve accuracy in forest ecosystem carbon accounting.

Methodological limitations include potential errors from whole excavation and soil augering, particularly for fine roots. However, compared with other time-consuming, labor-intensive methods that also cannot guarantee zero loss, these methods yield acceptable results when performed carefully [3,4].

References

[1] Canadell J, Jackson R B, Ehleringer J B, Mooney H A, Sala O E, Schulze E D. Maximum rooting depth of vegetation types at the global scale. *Oecologia*, 1996, 108(4): 583-595.
[2] Dannowski M, Block A. Fractal geometry and root system structures of heterogeneous plant communities. *Plant and Soil*, 2005, 272(1/2): 61-76.
[3] Root ecology. *Chinese Journal of Plant Ecology*, 2008, 32(6): 1213-1216.
[4] Underground ecology under global change: issues and prospects. *World Forestry Research*, 2004, 49(13): 1226-1233.
[5] Advances in plant root biology research. *World Forestry Research*, 2015, 28(3): 13-18.
[6] Combined effects of lanthanum and acid rain on soybean seedling root growth and nitrogen nutrition. *Journal of Plant Ecology*, 2013, 26(5): 25-29.
[7] Advances in forest ecosystem root biomass research. *Acta Ecologica Sinica*, 2014.

[8] Biomass and carbon storage of evergreen broadleaf ecological public welfare forests in Zhejiang Province. *Acta Ecologica Sinica*, 1999, 19(2): 270-277.

[9] Wu S T. Comparison of underground biomass and carbon-nitrogen storage at different successional stages of primary broadleaf-Korean pine forests in Changbai Mountains. *Chinese Journal of Applied Ecology*, 2005, 25(9): 2139-2144.

[10] Biomass measurement of *Pinus massoniana* forests in Huitong, Hunan. *Scientia Silvae Sinicae*, 1982, 18(2): 127-134.

[11] *Cunninghamia lanceolata* forest ecosystem science. Science Press, 2003: 15-16.

[12] *Pinus massoniana* in China. China Forestry Publishing House, 2001: 53-60.

[13] Biomass of Chinese fir plantations. *Journal of Zhejiang Forestry College*, 1991, 8(3): 21-27.

[14] Structure and distribution of biomass in natural secondary *Pinus massoniana* forests. *Journal of Hebei Agricultural University*, 2006, 29(5): 37-43.

[15] Carbon storage and dynamics of *Pinus massoniana* and eucalyptus plantations in Luocheng, Guangxi. *Ecology and Environmental Sciences*, 2011, 20(11): 1608-1613.

[16] Review of forest biomass models. *Journal of Northwest Forestry University*, 2008, 23(2): 58-63.

[17] Forest vegetation carbon storage dynamics in Sichuan and Chongqing (2000-2050) based on biomass density-age relationships. *Chinese Journal of Applied Ecology*, 2010, 21(12): 3036-3046.

[18] Selection of biomass estimation models for Chinese fir plantations. *Chinese Journal of Applied Ecology*, 2010, 28(3): 966-975.

[19] Biomass and productivity of Chinese fir plantations. *Chinese Agricultural Science Bulletin*, 2008, 40(7): 587-594.

[20] Xu B, et al. Biomass and carbon density of China's forests in 2000 predicted based on biomass density-age relationships. *Acta Ecologica Sinica*, 2008, 28(3): 96-975.

[21] Biomass of Chinese fir plantations. *Chinese Agricultural Science Bulletin*, 2009, 25(5): 97-103.

[22] Root biomass and distribution patterns of Yunnan pine forests. *Chinese Journal of Applied Ecology*, 2005, 16(1): 21-24.

[23] Leuschner C, Hertel D, Schmid I, Koch O, Muhs A, Hölscher D. Stand fine root biomass and fine root morphology in old-growth beech forests as a function of precipitation and soil fertility. *Plant and Soil*, 2004, 258(1): 43-56.

[24] Schenk H J, Jackson R B. The global biogeography of roots. *Ecological Monographs*, 2002, 72(3): 311-328.

[25] Root biomass of *Pinus massoniana* plantations at different densities. *Scientia Silvae Sinicae*, 2011, 47(3): 75-81.

[26] Root biomass and spatial distribution of *Pinus massoniana* plantations at different densities. *Journal of Central South University of Forestry and Technology*, 2014, 34(6): 71-75.

[27] Root biomass of major forest ecosystems in Changbai Mountains. *Journal of Shenyang Agricultural University*, 1998, 29(3): 229-232.

[28] Burton A J, Pregitzer K S, Hendrick R L. Relationships between fine root dynamics and nitrogen availability in Michigan northern hardwood forests. *Oecologia*, 2000, 125(3): 389-399.
[29] Root biomass and carbon storage of typical vegetation communities in red soil hilly regions. *Journal of Soil and Water Conservation*, 2009, 23(6): 134-138.

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