Growth and nutrient characteristics of *Pinus massoniana* in a Southern red soil

Chen Yishan¹, Zhang Qiaoling²,³*, Feng Liujun²,³
1. The Affiliated High School of Fujian Normal University, Fuzhou, FuJian 350007, China;
2. Key Laboratory for Subtropical Mountain Ecology (Ministry of Science and Technology and FuJian Province Funded), Fuzhou, FuJian 350007, China
3. College of Geographical Sciences, Fujian Normal University, Fuzhou, Fujian 350007, China

Corresponding author’s e-mail address: Zhangql17@163.com

Abstract: The aim of the present study was to provide a reference that could facilitate vegetation restoration activities in Southern red soil regions of China. We investigated the growth and nutrient characteristics of *Pinus massoniana*. We measured plant heights and diameters at breast height and collected organ samples in three plots in Huangnikeng in Zhuotian Town, Changting County, Fujian Province. There were mostly positive correlations among all *Pinus massoniana* growth indices, although the correlation between plant height and leaf biomass was negative. Conversely, nutrient concentrations among *Pinus massoniana* bark, trunk, leaves, branches, and roots differed greatly. The C concentrations of various *Pinus massoniana* organs were ranked as leaves > bark > branches > trunks > roots; N concentrations, leaves > roots > branches > bark > trunks; P concentrations, leaves > roots > branches > bark > trunk; and K concentrations, roots > leaves > bark > branches > trunk. C:N, C:P, C:K, and N:P were significantly different in different *Pinus massoniana* organs. The results suggest that the biomass of each organ in *Pinus massoniana* decreased in the order of trunk, branch, roots, and leaves, and the nutrient concentrations decreased in the order of leaves, roots, bark, branch, and trunk.

1. Introduction

Southern red soil regions in China experience the most severe and widespread soil erosion in the country, with an erosion intensity and scale only second to those in the Loess Plateau[1]. Southern soil regions in the country cover 1.13 million km², accounting for 11% of China’s land area[2]. According to some studies, soil fertility has declined and ecological environments have been degraded in the Southern red soil regions of China because of surface soil losses, which have, in turn, negatively affected the sustainable development of the local economies[3]. As a typical tree in Southern red soil regions of China, *Pinus massoniana* is a pioneer tree species used in local ecological restoration programs[4]. However, most of the current studies on *Pinus massoniana* have focused on its C storage characteristics[5], forest-soil nutrient coupling[6], and heavy metal concentration characteristics[7]. In areas with severe soil erosion in Southern China, the *Pinus massoniana* secondary forest ecosystems in different years of recovery exhibit variable C storage characteristics. For example, Liu et al. reported that in 10-, 20-, and 30-year-old *Pinus massoniana* secondary forests were higher than bare land trees, but they were still lower than natural secondary forests[5]. In addition, Liu et al. investigated the nutrient characteristics and ecological stoichiometric characteristics of *Pinus massoniana* leaves[8].
The objectives of the present study were to provide a reference for vegetation restoration in a Southern red soil zones in China. In the present study, we investigated the growth and nutrient characteristics of different *Pinus massoniana* organs in a Southern red soil area in China.

2. Materials and methods

2.1. Study area

A representative study site was selected in Huangnikeng (HNK), Hetian Town, in the middle of Changting County (116°16'52″ E–25°31'49″ N). Changting County is located in the west of Fujian Province, Southern China. The landforms in the region consist mainly of hills and low mountains. The region experiences a subtropical monsoon climate with warm and humid characteristics. The mean precipitation is 1885 mm/year and annual temperature is 18.5 °C. The majority of precipitation occurs during the summer months (June to August) with high-intensity storms associated with typhoons during the period. The dominant vegetation are *Dicranopteris dichotoma*, *Pinus massoniana*, *Liquidambar formosana*, *Schima superba*, and *Paspalum wettsteinii*, among others [9].

2.2. Methods

We selected three representative plots (20 × 20 m) in HNK and three typical *Pinus massoniana* plants along the diagonal of each plot. Plant height and diameter at breast height (DBH) of *Pinus massoniana* were measured using an altimeter and a DBH ruler, respectively. Leaves and branches were collected from the east, south, west, and north sides of *Pinus massoniana* trees using shears. We cut barks with a sickle and obtained the cores of trunk at breast high for *Pinus massoniana* by 5-mm diameter increment borer.. Subsequently, all samples were sent to the laboratory to be assayed.

According to Zeng Weisheng’s study, the biomass of *Pinus massoniana* estimated using a Binary Series Biomass Model System [10]. The biomass of the four sub-organs, namely, trunk, bark, branch, and leaves, are the weight variables of the weighted regression equation. The binary models are 1/D^{2.09}, 1/D^{1.78}, 1/D^{1.90}, and 1/D^{1.17}:

\[
M_A = 0.078596D^{2.1255}H^{0.40965} \tag{1}
\]

\[
M_B = 0.0084992D^{2.37212}H^{0.40965} \tag{2}
\]

\[
M_T = M_A + M_B \tag{3}
\]

where \(M_A, M_B, M_T, M_p, M_s, M_b, \) and \(M_l\) represent above ground biomass (kg), belowground biomass (kg), total biomass (kg), bark biomass (kg), trunk biomass (kg), branch biomass (kg), and leaf biomass (kg), respectively. \(D\) and \(H\) represent DBH (cm) and plant height (m) of *Pinus massoniana*, respectively.

2.3. Statistical analysis

All data collations were conducted using MS EXCEL 2016 (Microsoft Corp., Redmond, WA, USA), and all analyses were performed using IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) were performed to examine the differences in biomass among \(M_A, M_B, \) and \(M_T\) and the differences in biomass among \(M_p, M_s, M_b, \) and \(M_l\). Similarly, ANOVA was used to examine the differences in C, N, P and K concentrations and the C:N, C:P, C:K, N:P, N:K and P:K ratios in each *Pinus massoniana* organ. The differences in group means were tested using the least-significant difference test with a significance level of \(P < 0.05\). Correlation analysis was performed to evaluate the relationships among DBH, plant height, plant density, \(M_p, M_s, M_b, M_A, M_B, \) and \(M_T\) with Pearson correlation coefficients. All illustrations were generated using Origin 9.0 (OriginLab Corp., Northampton, MA, USA).

3. Results

3.1. Growth characteristics of *Pinus massoniana*
The average *Pinus massoniana* DBH, plant height, and plant density were 7.55 ± 0.56 cm, 7.18 ± 1.15 m, and 0.44 ± 0.08 plant/m² (mean ± SD), respectively.

![Figure 1](image-url)  
**Figure 1** Biomass in different parts of *Pinus massoniana*

Different letters indicate significant differences at *P* < 0.05.

*Pinus massoniana* Mₐ and Mₜ were significantly higher than Mₖ (*P* < 0.05), but there were no significant differences between Mₐ and Mₜ (Fig. 1[1]). The average Mₐ, Mₖ, and Mₜ were 15.48 ± 2.84 kg, 2.30 ± 0.46 kg, and 17.78 ± 3.30 kg, respectively. Mₐ accounted for 87% of Mₜ, while Mₖ accounted for 13% of Mₜ.

Mₐ consisted of every organ in the aboveground parts of *Pinus massoniana* (Mₚ, Mₛ, Mₖ, and Mₜ). The average values of Mₚ, Mₛ, Mₖ, and Mₜ were 1.59 ± 0.33 kg, 8.68 ± 1.72 kg, 3.23 ± 0.74 kg, and 1.98 ± 0.66 kg (mean ± SD), respectively, and accounted for 10%, 56%, 21%, and 13% of Mₐ, respectively. The statistics indicated that Mₛ played an important role in Mₐ. Based on the results of ANOVA, Mₖ and Mₛ were significantly higher than Mₚ and Mₜ, and Mₖ was significantly higher than Mₛ, while there was no difference between Mₚ and Mₜ (*P* < 0.05) (Fig. 1[2]).

The results of correlation analyses indicated that most growth attributes of *Pinus massoniana* had significant correlation except density (Table 1). DBH was positively correlated with Mₚ, Mₛ, Mₖ, Mₐ, Mₖ, and Mₜ (*P* < 0.01). The coefficient of correlation between DBH and Mₖ was 0.997 and between DBH and Mₖ was 0.996. However, although plant height was negatively correlated with Mₖ (*P* < 0.01), plant height and density were not significantly correlated with the other growth attributes. There were positive correlations among different parts of *Pinus massoniana* (*P* < 0.01), although no significant correlations existed between Mₛ and Mₚ, Mₛ, and Mₜ. In addition, Mₖ was not significantly correlated with Mₐ, Mₖ, and Mₜ. In addition, there were significant correlations among Mₐ, Mₖ, and Mₜ (*P* < 0.01), the coefficients of correlations among them were all as high as 1.00.

**Table 1** Correlations among *Pinus massoniana* growth indicators

|                    | DBH  | Plant height | Plant density | Mₚ    | Mₛ    | Mₖ    | Mₜ    | Mₐ    | Mₖ    | Mₛ    | Mₜ    |
|--------------------|------|--------------|---------------|-------|-------|-------|-------|-------|-------|-------|-------|
| DBH                | 1.000| -0.503       | 1.000         | Mₚ    |       |       |       |       |       |       |       |
| Plant height       |      | 0.493        | 0.079         | 1.000 | Mₛ    | Mₖ    | Mₜ    | Mₐ    | Mₖ    | Mₛ    | Mₜ    |
| Density            |      |              |               | Mₚ    | 0.997**| -0.447| 0.533 | 1.000 |       |       |       |
| Mₚ                 |      |              |               | Mₛ    | 0.542 | 0.449 | 0.604 | 0.596 | 1.000 |       |       |
| Mₛ                 |      |              |               | Mₖ    | 0.996**| -0.444| 0.535 | 1.000 | 0.598 | 1.000 |       |
| Mₖ                 |      |              |               | Mₜ    | 0.880**| -0.843**| 0.249 | 0.846 | 0.081 | 0.846 | 1.000 |
| Mₜ                 |      |              |               | Mₐ    | 0.906**| -0.093 | 0.623 | 0.932* | 0.846**| 0.933**| 0.599 | 1.000 |
| Mₐ                 |      |              |               | Mₖ    | 0.917**| -0.120 | 0.620 | 0.942**| 0.831**| 0.942**| 0.621 | 1.000*|
| Mₖ                 |      |              |               | Mₛ    | 0.908**| -0.096 | 0.623 | 0.933**| 0.844**| 0.934**| 0.602 | 1.000*|
| Mₛ                 |      |              |               | Mₜ    |       |       |       |       |       |       |       |
| Mₜ                 |      |              |               |       |       |       |       |       |       |       |       |

**P** < 0.05; **P** < 0.01.
n = 9, *: Correlation is significant at the 0.05 level (2-tailed). **: Correlation is significant at the 0.01 level (2-tailed).

3.2. Nutrient characteristics of Pinus massoniana

According to our experimental results, there were significant differences in all nutrient variables among the five organs of Pinus massoniana (P < 0.05). The C concentrations in all P. massoniana organs were higher than 450 mg kg\(^{-1}\), and the order of concentrations from high to low was leaves, bark, branches, trunk, and roots. In addition, the concentrations in the bark, branches, and leaves were significantly higher than the concentrations in the trunk and roots (P < 0.05). The highest N concentrations among the five organs were in the leaves, while the lowest were in the trunks. Significant differences were observed in N concentrations among all the organs studied (P < 0.05); however, there were no significant differences in N concentrations between the branches and the roots. The order of P concentrations from high to low was leaves, roots, branches, bark, and trunk, and leaf P and roots P concentrations were significantly higher than in the other organs (P < 0.05). The order of K concentrations in the organs from the highest to the lowest was roots, leaves, bark, branches, trunk, and leaves. Among them, leaf K and root K concentrations were significantly higher than bark, trunk, and branch K concentrations (P < 0.05).

Some of the Pinus massoniana stoichiometric variables (C/N, C/P and C/K of all Pinus massoniana organs) exhibited similar distributions: the highest values were trunk C/N, C/P, and C/K, followed by the bark, branches, and roots, and the lowest in the leaves. Trunk C/N (898.12), C/P (2808.51), and C/K (214.76) were significantly higher than those in the bark, branches, leaves, and roots (P < 0.05), because trunk N (0.62 g kg\(^{-1}\)), P (0.19 g kg\(^{-1}\)) and K (2.78 g kg\(^{-1}\)) concentrations were all markedly lower than in the other organs. Among bark, branches, leaves and root, no significant differences were observed in C/N, C/P, and C/K. N/P and N/K in all Pinus massoniana organs displayed similar distributions, and
the order from high to low was branches, leaves, bark, trunk, and roots. Among them, branch and leaf N/P values were significantly different from those of the other organs ($P < 0.05$), while there were no significant differences in the N/K and P/K values across all organs.

Figure 3. Ecological stoichiometry of different *Pinus massoniana* organs
Different letters indicate significant differences at $P < 0.05$.

4. Discussion

4.1. Growth characteristics and their correlation in *Pinus massoniana*

Growth characteristic indicators include plant height, DBH, plant density, above-ground biomass, belowground biomass, and total biomass. Our findings revealed significant correlations among all growth characteristics except *Pinus massoniana* density. In addition, all indicators increased obviously due to change in DBH, while increased plant height led to a decrease in leaf biomass, and bark biomass increased because of an increase in branch biomass.

Biomass is the sum of organic matter accumulated in each organ per unit time. In addition, the distribution of biomass in organs, which is the ratio between an organ’s biomass and total biomass, is attributed to a balance between reproduction and survival in plant individuals. Therefore, it is essential to investigate the distribution plant biomass to reveal the status of plant organic matter accumulation\textsuperscript{11}. In our study, the biomass distribution ratio of the bark, trunk, branches, leaves, and roots were 8.94\%, 50.10\%, 18.19\%, 11.11\%, and 12.94\%. In addition, all the results were similar with the estimates of *Pinus massoniana* biomass modelled by Zeng Weisheng\textsuperscript{10}.

4.2. Nutrients characteristics in *Pinus massoniana*
Plants have to obtain nutrients from the soil to maintain their normal growth and development. As the most critical nutrient elements for plant growth and development, C, N, P, and K are involved in the metabolism and synthesis of related products during plant growth and development\(^{(11-12)}\). The concentrations of nutrients in plants can not only reveal plant species attributed but also the relationships and interactions between plant and soil. According to our results, the leaf C, N, and P concentrations were the highest but the trunk concentrations were the lowest. Leaf K concentrations were lower than root K concentrations, and trunk K concentrations were the lowest. The differences were due to the different physiological functions of each organ. Leaves are the main sites of photosynthesis and are essential for nutrient accumulation and metabolism in plants. The trunk, bark, and branches, however, are mainly organs that transfer nutrients from the soil to the leaves. Therefore, excluding the roots, leaf C, N, P, and K concentrations were higher than in other \textit{Pinus massoniana} organs\(^{(13)}\). The results are consistent with observation in typical plants in 7 forest ecosystem stations and 52 wetlands in China\(^{(14-15)}\). Another potential reason for the variation in the concentrations of nutrient across organs is that nutrients regulate the physiological functions in organs\(^{(4)}\). Our study showed that the nutrient concentrations in different organs were ranked as leaves > roots > bark > branches > trunk. Previous studies on the order of nutrient concentrations in organs have suggested that N, P, and K are ranked as leaves > roots > trunk\(^{(16)}\), which is similar to our research results. Nevertheless, several similar studies conducted in Guangxi\(^{(17)}\), Hunan\(^{(18)}\), and Anhui\(^{(19)}\) have reported different results in the following order: leaves > branches > bark > roots > trunk. The difference could be attributed to different environments. In our study region, \textit{Pinus massoniana} were grown in poor environment and nutrient-poor soils. Therefore, the \textit{Pinus massoniana} plants required to store high nutrient amounts in the roots to maintain growth.

5. Conclusions
In summary, we observed significant positive correlations among the growth indices of \textit{Pinus massoniana}, although there was a negative correlation between plant height and leaf biomass. The bark, trunk, leaf, branch, and root nutrient concentrations in \textit{Pinus massoniana} varied considerably, and there were significant differences in C, N, P, and K concentrations across organs. In terms of ecological stoichiometric ratios, there were significant differences across different \textit{Pinus massoniana} organs excluding N/K and P/K.

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