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Soil Physical and Chemical Properties of Pure *Pinus massoniana* and Its Mixed Forests in Different Ages in Southern Guangxi

Zhongming HAO[1], **Shuirong WU**[2], **Lin QIN**[1*], **Ling TAN**[1], **Wenfu GUO**[3]

1. College of Forestry, Guangxi University, Nanning 530004, China; 2. Research Institute of Forestry Policy and Information, Chinese Academy of Forestry, Beijing 100091, China; 3. Experimental Center of Tropical Forestry, Chinese Academy of Forestry, Pingxiang 532600, China

Abstract Six forest stands of 59, 34 and 24 year-old *Pinus massoniana* forests and their mixed forests were selected at the Experimental Center of Tropical Forestry of Chinese Academy of Forestry, and 20 m × 20 m plot was set up and soil samples were taken from 0 – 60 cm soil layers, to analyze the changes of soil nutrient content under different forest stands and forest ages. The results showed that soil moisture and the bulk density in the mesophytic forest land were higher than those of other forest lands. The highest soil porosity value was observed in the early forest land. Soil pH of different forest was 4.45 – 4.75, indicating the variation was small. Besides, it indicated that the mixed forest was more able to increase the soil fertility than the pure forest because that the variation of soil acidity, organic matter content and total P and K in 34 and 24 year-old mixed forests were higher than those in pure forests of the same year old. However, the content of soil available P and K decreased with the increase of soil depth, and varied in terms of forest ages. From the changes of soil indicators in different forest lands, soil nutrients in the 34 year-old *P. massoniana* forest was superior to that of other forest stands.

Key words *Pinus massoniana*, Soil physical and chemical properties, Monoculture plantations, Mixed plantations

1 Introduction

At present, at both home and abroad, the general trend of forest soil research is to study the relationship between forest soil quality evolution and soil function changes. From the current situation of world forestry development, the area of natural forest is gradually shrunk, and the area of mixed plantation is gradually increasing[1]. Extensive studies have shown that mixed forests can effectively increase the stand productivity[2]. It is reported that the 47 year-old European pine forests built in Russia have stock volume of 260 m^3/ha, and the mixed forests of European pine and eucalyptus forests have stock volume up to 610 m^3/ha, and the growth of mixed forests is much greater than that of pure forests[3]. Mixed forests can effectively improve the ecological conditions of the stand, improve the stability of the stand, bring into a better play of the forest protection benefit, improve the site conditions, and are favorable for improving the microclimate in the forest and improve the soil fertility. Compared with natural forests, plantations have some defects in composition and stand structure, which will, to some extent, affect the biodiversity, soil fertility and stand productivity of the area[4 – 7].

In the south subtropical regions of China, the long-term monoculture plantation mode of *Cunninghamia lanceolata* and *Pinus massoniana*, and the rapid development of short-cycle industry-oriented plantation of Eucalyptus in the past 20 years have led to the decline of soil fertility and productivity. These problems restrict the sustainable use of forest land[8 – 10]. Since the 1980s, most studies have focused on the effects of different types of plantation regeneration on soil physical and chemical properties[11 – 12]. In this study, taking Experimental Center of Tropical Forestry of Chinese Academy of Forestry in Pingxiang City of Guangxi Zhuang Autonomous Region as the experiment site, and different year-old *P. massoniana* forests and their mixed forests as research objects, we compared the soil physical and chemical properties of different soil layers, in order to accurately recognize and evaluate their characteristics and provide a scientific basis for proper operation of plantations and proper selection of land use types in this region.

2 Materials and methods

2.1 Experimental materials The study area is in Fubo Experiment Site (22°02′ – 22°04′ N, 106°51′ – 106°53′ E) of Experimental Center of Tropical Forestry of Chinese Academy of Forestry in Pingxiang City of Guangxi. The landform type is mainly low mountains and hills, with an altitude of 430 – 680 m, and the zonal soil is mountain red soil. It belongs to the south subtropical monsoon type humid and semi-humid climate, with long sunshine time, plentiful rainfall, and distinct dry and rainy seasons (dry season is from October to March of the next year and rainy season is from April to September). The six different forest types include three *P. massoniana* pure forests and three *P. massoniana* mixed forests and other broad-leaved species. The afforestation years of the three *P. massoniana* forests were 1958, 1983 and 1993, respectively. Both the 59 year-old *P. massoniana* forest (forest 1) and the 34 year-old *P. massoniana* forest (forest 2) experienced three times of thinning, while the 24 year-old *P. massoniana* (forest 3) experienced only one time of thinning. The three mixed forests are 59 year-old *P. massoniana* and 34 year-old *Dysoxylum* spp. (forest 4), 34 year-old *P. massoniana* and *Dysoxylum* spp. (forest 5), and 24 year-old *P. massoniana* and 7 year-old

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* Corresponding author. E-mail: 15754886046@163.com

Dysoxylum spp. and *Michelia hedyosperma* (*forest* 6). The mixed forest of 59 year-old *P. massoniana* and 34 year-old *Dysoxylum* spp. (forest 4) experienced three times of thinning.

2.2 Experiment methods

2.2.1 Collection of samples. According to different slope positions (upper, middle and lower), we set each forest type with a plot with size of 20 m × 20 m. In each plot, we selected three points on the diagonal, excavated the soil profile by 0 – 20, 20 – 40, and 40 – 60 cm. After the same layer soil was fully mixed, we collected soil samples by quarter method and divided soil samples into two parts: one was put into polyethylene freshness protection bag and stored in a biological ice pack, and the other was put into a cloth bag. At the same time, we used cutting ring (with capacity of 100 cm^3) and an aluminum box to collect soil samples.

2.2.2 Determination of indicators. The physical properties such as soil moisture content, bulk density and porosity were determined by the cutting ring method (GB7835-87); the soil pH was determined by the potential method (GB7859-87). The total organic carbon content of the soil was determined using a MultiN/C 3400-HT1300 organic carbon total nitrogen analyzer (Analytik Jena, Germany). The total P and total K of the soil were digested with H_2SO_4-$HClO_4$, and the P in the soil was converted into the orthophosphate form. The P content in the digested solution was determined by SmartChem 200 automatic chemical element analyzer, and the K content was determined by flame photometer. The available P content in the soil was determined by SmartChem 200, extracted with 0.05 mol/L of HCl-0.025 mol/L of 1/2 H_2SO_4, the water-soil ratio was 5∶1 (GB7853-87); the available K content was diluted with 1 mol/L of ammonium acetate, and determined by a flame photometer, and the water-soil ratio was 10∶1 (GB7859-87).

2.2.3 Data analysis. The data were processed by Excel 2007. SPSS22.0 software was used for one-way analysis of variance (*ANOVA*) and least significant difference (*LSD*) to test the difference of soil physical and chemical properties between different soil layers or different forest stands.

3 Results and analysis

3.1 Soil physical properties of pure and *P. massoniana* mixed forests

3.1.1 Soil moisture. According to Fig. 1, both the pure and *P. massoniana* mixed forests, the soil moisture was 34 year-old *P. massoniana* forest > 59 year-old *P. massoniana* forest > 24 year-old *P. massoniana* forest, which may be associated with the plant diversity and litter under the forest. Through the field sampling, we found that the vegetation and the amount of litter on the ground of the 34 year-old *P. massoniana* and *Dysoxylum* spp. mixed forest were significantly higher than those of the other two forest stands. The litter is favorable for maintaining water, inhibiting surface evaporation and increasing the soil moisture of the surface layer[13 – 14].

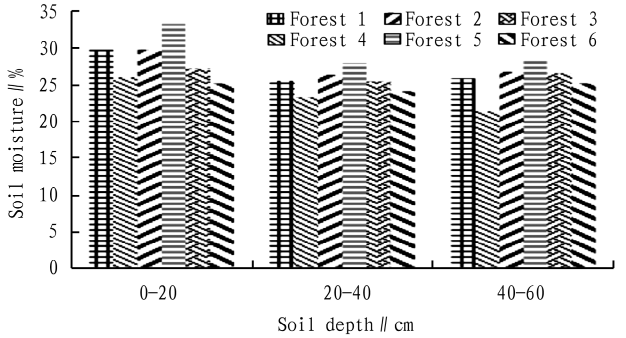

Fig. 1 Comparison of soil moisture between different ages of *Pinus massoniana* forests and their mixed forests

3.1.2 Bulk density. According to Fig. 2, the soil content of the middle layer (20 – 40 cm) and the bottom layer (40 – 60 cm) of each stand was greater than the surface layer of each layer. By comparison, the bulk density of surface soil was the smallest, indicating that the soil surface is relatively loose, which may be associated with the accumulation of surface litter and the decomposition of microorganisms in the forest soil. Due to the action of microorganisms, the surface litter is decomposed, and the humus content in the soil is increased after rot, and the soil structure tends to become agglomerate structure[15 – 17], because small pores are formed between the single grains, and large pores are formed between the agglomerates, and compared with the single grain structure, the total porosity is large and the bulk density is small.

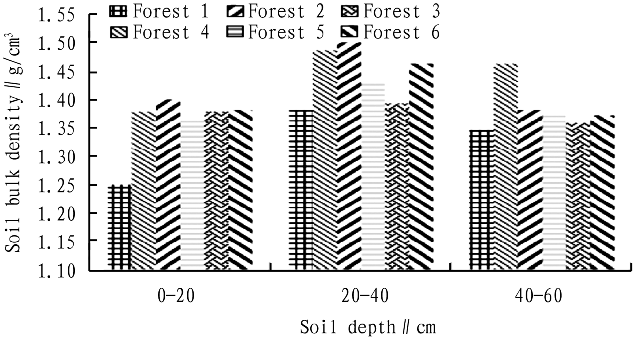

Fig. 2 Comparison of soil bulk density between different ages of *Pinus massoniana* forests and their mixed forests

3.1.3 Porosity. According to Fig. 3, the soil porosity of the soil layer (0 – 20 cm) and the bottom layer (40 – 60 cm) of each forest was greater than that of the middle layer (20 – 40 cm). By comparison, the surface soil had the largest porosity, indicating that the soil surface is loose. The soil porosity of the soil layers of the 59 year-old *P. massoniana* forest was greater than that of the mixed forest, while other ages of the *P. massoniana* mixed forests had soil porosity greater than that of the pure forest. This indicates that in the same age of forest, mixed forest can effectively improve the aeration and water permeability of the soil, make the soil texture become loose, increase the aggregate structure, and increase the porosity, accordingly accelerating the plant's utilization of forest nutrient transformation and absorption rate, greatly promoting the absorption function of the roots, which is favorable for the growth and development of ground parts.

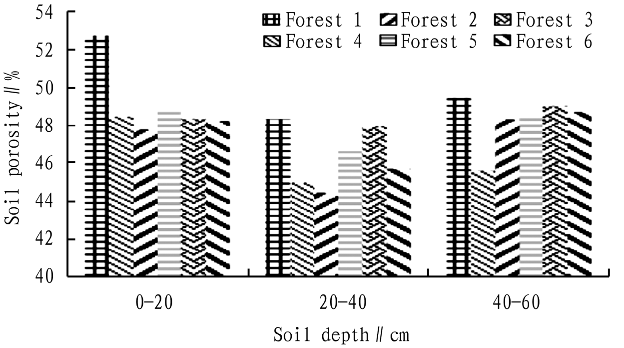

Fig. 3 Comparison of soil porosity between different ages of *Pinus massoniana* forests and their mixed forests

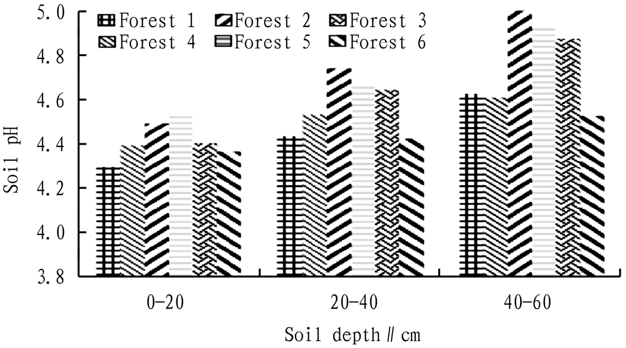

Fig. 4 Comparison of soil pH between different ages of *Pinus massoniana* forests and their mixed forests

3.2 Soil chemical properties of pure and *P. massoniana* mixed forests

3.2.1 The soil pH. According to Fig. 4, the soil pH of the six stands was in the range of 4.35 – 4.95 and the changes were not significant, but the soil pH of the 34 year-old *P. massoniana* forest was higher than the other two ages of forests. From the *P. massoniana* pure forest, the soil pH of each layer of 34 year-old *P. massoniana* was significantly higher than other two ages of forests. pH can directly reflect soil acidity and alkalinity and is one of the essential factors affecting soil nutrients, directly affecting the existence, transformation and effectiveness of soil nutrients[18 – 19]. According to preliminary analysis, the mature forest of 59 year-old *P. massoniana* is rarely influenced by humans, and has a thick humus layer, and this forest has a large degree of canopy closure and less grass under the forest, which may be the main reason for its low soil pH.

3.2.2 Organic matter content. According to Table 1, the changes in soil organic matter in each layer of the six stands were consistent, that is, surface soil > middle soil > bottom soil, and the difference between the soil layers was significant. The surface soil is loose and well ventilated, and the root system is densely distributed in the surface soil, the temperature is relatively high, and the microbial activity is frequent. The litter is decomposed to form a large amount of humus, accordingly leading to high organic matter content. With the increase of the soil layer, the lower layer soil undergoes the process of soil formation, and the distribution of animal and plant residues such as litter in this layer is gradually reduced, and the nutrient content is accordingly reduced[12, 20 – 21]. For the same age forests, 34 year-old *P. massoniana* and *Dysoxylum* spp. mixed forest were higher than the same year-old *P. massoniana* pure forest, but the difference was not significant, and 24 year-old and 59 year-old forest stands did not show such rules of changes.

Table 1 Soil organic matter content and nutrient content of different ages of *Pinus massoniana* forests and their mixed forests

Indicator	Soil depth cm	59-year old *P. massoniana* pure forest	Mixed forest of 59-year old *P. massoniana* and different ages of *Dysoxylum* spp.	34-year old *P. massoniana* pure forest	Mixed forest of 34-year old *P. massoniana* and the same age of *Dysoxylum* spp.	24-year old *P. massoniana* pure forest	Mixed forest of 24 year-old *Dysoxylum* spp. and different ages of *M. hedyosperma*
Organic matter content // g/kg	0 – 20	30.28 ± 13.49 abA	24.33 ± 3.85 bA	34.07 ± 3.14 abA	40.52 ± 6.83 aA	27.32 ± 2.42 abA	30.66 ± 3.46 abA
	20 – 40	10.89 ± 0.58 bB	11.47 ± 1.23 bB	13.58 ± 2.19 abB	16.74 ± 3.10 aB	14.29 ± 3.46 abB	12.24 ± 0.84 abB
	40 – 60	10.27 ± 1.39 aB	9.72 ± 0.29 aC	8.70 ± 2.20 aC	11.35 ± 1.66 aC	11.48 ± 0.60 aC	10.55 ± 0.97 aC
Total P content // g/kg	0 – 20	0.12 ± 0.01 bA	0.18 ± 0.02 abA	0.18 ± 0.04 abA	0.20 ± 0.04 aA	0.15 ± 0.03 abA	0.17 ± 0.01 abA
	20 – 40	0.11 ± 0.02 bA	0.16 ± 0.01 abA	0.16 ± 0.01 abA	0.18 ± 0.05 aA	0.16 ± 0.01 abA	0.14 ± 0.02 aA
	40 – 60	0.24 ± 0.15 aA	0.16 ± 0.01 aA	0.18 ± 0.02 aA	0.15 ± 0.02 aA	0.15 ± 0.02 aA	0.15 ± 0.01 aA
Total K content // g/kg	0 – 20	0.74 ± 0.07 aA	0.67 ± 0.07 aA	0.63 ± 0.11 aA	0.84 ± 0.05 aA	0.79 ± 0.17 aA	0.66 ± 0.11 aA
	20 – 40	0.77 ± 0.04 aA	0.58 ± 0.06 aA	0.77 ± 0.10 aA	0.80 ± 0.03 aAB	0.90 ± 0.24 aA	0.61 ± 0.12 aA
	40 – 60	0.82 ± 0.16 aA	0.68 ± 0.03 aA	0.77 ± 0.09 aA	0.77 ± 0.05 aB	0.85 ± 0.10 aA	0.68 ± 0.18 aA
Available P content // mg/kg	0 – 20	1.36 ± 0.25 bcA	1.74 ± 0.52 bA	2.96 ± 0.28 aA	0.84 ± 0.14 cA	2.34 ± 0.50 abA	1.17 ± 0.30 bcA
	20 – 40	0.70 ± 0.20 cB	1.16 ± 0.24 bB	2.04 ± 0.09 aAB	0.34 ± 0.10 cB	1.27 ± 0.30 bB	0.36 ± 0.13 cB
	40 – 60	0.61 ± 0.10 cB	0.84 ± 0.06 bcB	2.00 ± 0.22 aB	0.40 ± 0.07 cB	0.92 ± 0.15 bB	0.23 ± 0.10 cB
Available K content // mg/kg	0 – 20	27.07 ± 8.23 aA	14.43 ± 5.41 bA	15.57 ± 2.52 abA	17.07 ± 0.66 abA	24.7 ± 5.59 abA	24.83 ± 4.48 abA
	20 – 40	18.47 ± 6.06 aA	12.23 ± 4.86 aA	11.63 ± 1.38 aB	14.33 ± 7.42 aA	13.87 ± 1.47 aB	24.07 ± 7.65 aA
	40 – 60	17.37 ± 2.83 abA	11.33 ± 1.59 bA	9.20 ± 1.35 bB	10.30 ± 0.49 bA	15.03 ± 4.78 abA	18.03 ± 4.29 aA

Note: the different small letters in the same column data indicate significant difference, while different capital letters means extremely significant difference.

3.2.3 Total P and available P content. According to Table 1, the total P content of the six stands was greater in the surface layer than that of the middle layer, and the difference was not significant. For the same age forests, the difference was not significant.

The total P content of the upper and middle soil layers of the stand showed that the mixed forest was greater than the pure forest, and the total P content of the lower layer was pure forest ≥ mixed forest. For the *P. massoniana* pure forest, the difference was not significant, 34 year-old pure forest > 24 year-old pure forest > 59 year-old pure forest. Among the six different forest layers, the available P content decreased with the increase of soil depth, and the difference between the surface layer and the middle layer and the bottom layer of each forest was significant, while the difference between the middle layer and the bottom layer was not significant.

For different ages of pure forests, the P content of each soil layer showed obvious rules, characterized by 59 year-old pure forest > 24 year-old pure forest > 34-year-old pure forest. Among them, the difference between 34 year-old pure forest surface soil and bottom soil was significant with other two forest stands. For different ages of mixed forests, the 24 year-old mixed forest > 34 year-old mixed forest > 59 year-old mixed forest, the difference between the bottom layer soil of the 24 year-old mixed forest and the other two forest stands, the difference between other remaining forests was not significant.

3.2.4 Total K and available K content. According to Table 1, the total K content of the six stands had no regular rules of changes, and the difference was not significant. For the same age forests, the 59 year-old and 24 year-old stands had higher total K content in all soil layers of mixed forests than in pure forests, while the total K content in the 34 year-old mixed forests was higher than that the same age pure forests. For the *P. massoniana* pure forest, the total K content of the soil was 24 year-old pure forest > 59 year-old pure forest > 34 year-old pure forest, while the total K content of the upper and lower soil of the *P. massoniana* mixed forest was 34 year-old pure forest > 59 year-old pure forest > 24 year-old pure forest, the total K content of the middle layer soil was 34 year-old pure forest > 24 year-old pure forest > 59 year-old pure forest.

Among different soil layers, the content of available K in six forest stands decreased with the increase of soil depth; specifically, the upper and middle soil layers of 34 year-old and 24 year-old *P. massoniana* forests were significantly different, while the difference in available K content between soil layers of other stands was not significant. For the same age stands, the soil available K content of 59 year-old pure forest was greater than that of the 59 year-old mixed forest, and the upper soil content was significantly different. The 34 year-old and 24 year-old *P. massoniana* forests showed the available K of the mixed forest was greater than that of the pure forest, but the difference was not significant.

4 Conclusions and discussions

According to the results of this study, the surface soil is significantly better than the middle layer soil in terms of soil moisture, bulk density and porosity. Compared with the *P. massoniana* mixed forests and mixed forests, the 34 year-old and 24 year-old *P. massoniana* mixed forests are significantly better than the *P. massoniana* pure forests, indicating that *P. massoniana* mixed forests are favorable for storage of soil water and can improve soil looseness.

In terms of soil chemical properties, except for the soil pH of 59 year-old *P. massoniana* mixed forests in all soil layers higher than that in the same age *P. massoniana* pure forests, the soil pH of others is smaller in *P. massoniana* mixed forests than in *P. massoniana* pure forests, indicating that the improvement of mixed forests in soil acidity is not significant in a short term. For the *P. massoniana* pure forests, the soil pH of the 34 year-old *P. massoniana* forests is significantly higher than the other two ages, and the difference is significant; the same situation occurs in the *P. massoniana* mixed forests. Therefore, we believe that this is caused by different degrees of human disturbance in each forest age. The 34 year-old *P. massoniana* is greatly affected by human disturbance[20-21], and the vegetation under forest is richer than the other two age forests, and the species is more diverse, accordingly the pH is high.

Among different soil layers, the content of available K in six forest stands decreases with the increase of soil depth. Although the soil chemical properties of each stand have certain rules of changes with the deepening of the soil layer, they do not show the same trend in the *P. massoniana* pure forests and their mixed forest. The factors affecting the chemical properties of the soil are diverse and the process is complex. The chemical properties of the soil interact with the growth and development of the plants. The difference in the quantity and quality of the litter is also an important reason for the difference in soil nutrient content of different forests.

Although the comparison of the *P. massoniana* pure forests and mixed forests with the same age did not show the same rules of changes, most of the soil physical and chemical properties showed that the *P. massoniana* mixed forests had certain improvement effects on soil physical and chemical properties. Compared with the pure forest, *P. massoniana* mixed forests have higher species diversity and richer litter species, and the nutrient decomposition ability and transformation rate are faster, thus improving soil fertility and soil structure, which is more favorable for plant growth of mixed forests. Finally, the differences in soil chemical properties between the *P. massoniana* pure forests and mixed forests need further study, so as to provide a scientific basis for accurately assessing the effects of *P. massoniana* mixed plantation on the soil fertility.

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slight increase rank third, regions with significant increase rank fourth, and regions with significant decline are the fewest. Furthermore, there are great differences in the spatial distribution of NPP variations in Guangxi. Regions with slight decline of NPP are mainly distributed in the northeastern Guangxi; regions with slight increase of NPP are mainly distributed in the southern Guangxi, and regions with basically stable NPP are mainly distributed in southeastern Guangxi. Variations of vegetable NPP are joint results of natural factors and social and economic activities. In this study, we simply analyzed the spatial and temporal distribution patterns of NPP without combining the temperature, precipitation, and soil. Therefore, it is necessary to make further study about the driving mechanism of the vegetable NPP.

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