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Influences of species mixture on biomass of Masson pine (*Pinus massoniana* Lamb) forests

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ABSTRACT. The effect of tree diversity on productivity in subtropical forests in China is poorly understood. We investigated the biomasses of trees, understory vegetation, coarse roots, and fine roots with varying proportions of *Pinus massoniana*, mixed with other tree species in stands of the same age, to examine the effects of tree diversity. With an increase of *P. massoniana* proportion, the tree and understory biomasses increased at first, and then gradually decreased. As expected, the biomass of fine roots decreased with soil depth. Stands with 40 to 60% *P. massoniana* had the highest biomass, whereas stands with <20% *P. massoniana* had the least biomass. Stands with <20% *P. massoniana* had the least understory biomass, whereas those with 20 to 40% Masson pine had the least fine root biomass.

Key words: *Pinus massoniana*; Mixed forest; Biomass; Undergrowth; Arboreal stratum

INTRODUCTION

The diversity-productivity relationship of trees has received considerable attention during the past two decades, largely because a long-term pure stand production system is not sustainable owing to the decline in soil fertility and productivity (Hooper et al., 2005). Numerous empirical experiments have shown that diversity, which is also defined as the biodiversity effect, has positive relationships with productivity, meaning that polycultures have higher production biomass than the average production of monocultures (Tilman et al., 1996; Loreau et al., 2001; Cardinale et al., 2007; Isbell et al., 2009). Polycultures have the advantages of species complementation, an improved ecosystem, and higher productivity. It is well known that a good mixed plantation can improve environmental conditions, increase the stability of a forest, and maintain high productivity. These benefits accrue because coexisting species occupy different ecological niches, resulting in more complete resource usage (Tilman et al., 1996; Loreau et al, 2001; Spehn et al., 2005; Marquard et al., 2009). The Niche Complementarity Hypothesis, the cornerstone of diversity-productivity relationship studies, explains that the biodiversity effect is due to increased resource use and nutrient retention via niche differentiation or partitioning and interspecies facilitation (Tilman, 1999; Loreau et al., 2001; Hooper et al., 2005). However, it is rare, when considering the influences of species mixture on biomass changes, to directly demonstrate the link between the mixed ratio effect and biomass and productivity.

The factors discussed above can assist in identifying target species capable of inhabiting vacant forest niches, so that tree productivity would be maintained. This will also help maintain the tree composition of the forest during stand development (Pande, 2005). Studies have shown that understory vegetation refers to all plants, including shrubs, herbs, and vines, growing under the forest canopy. This understory vegetation is an important component of the forest ecosystem, playing a crucial role in improving the soil, preventing water and soil losses, and maintaining diversity and material recycling. Understory vegetation is also an important component of the forest carbon mass. Fine root biomass is closely related to the species and ages of trees in a stand. A mixed woodlot generally has a higher standing biomass than a pure stand. The biomass of fine roots (< 2 to 5 mm in diameter) varies between 46 and 2805 g/m^2. The fine root biomass in a forest ecosystem depends on the tree species, weather, site type, soil, community structure, and tree age. Fine roots are the important dynamic component of nutrients, playing an essential role in energy flow and material cycling in a forest ecosystem (Usman et al., 2000). In many stands, over 50% of the primary production is used in fine root maintenance (Fogel and Hunt, 1979; Grier et al., 1981; Jackson et al., 1997). Through their circulation within the fine roots, soil carbon and nutrient return may equal, and even exceed, that of the above-ground litter (Arthur and Fahey, 1992; Pregitzer et al., 1993). If the production of root biomass, especially the fine root biomass, is neglected, then the organic and nutrient turnovers will be underestimated by 20% (Vogt et al., 1986). Therefore, fine roots are an important "currency" in forest primary production (Hendrick and Pregitzer, 1993; Gill and Jackson, 2000), and the key to the study of biomass in the forest ecosystem.

The current study analyzed the biomass of different layers in mixed stands with Masson pine comprising <20%, 20 to 40%, 40 to 60%, 60 to 80%, and >80% of this pine species present. The purpose of this study was to identify the optimal proportion of Masson pine in mixed stands in which maximal biomass can be obtained. This information is necessary for the establishment of commercial management of Masson pine carbon currency stands.

MATERIAL AND METHODS

Study area

Study sites were located on the southeast edge of Dabieshan Mountain (31°01' to 31°38'N, 117°05' to 117°43'W), close to Zong Yang County, Anhui Province, China. The area has a subtropical wet monsoon climate with four distinct seasons. The mean annual temperature is 16.5°C, the mean annual sunshine is 2064.9 h, and the mean annual precipitation is 1326.5 mm. The rock base is mainly granite gneiss, and the soil is granite yellow brown soil, with a pH of 5.5 to 6.5. The barren soil has a weak capacity to hold water. In order to ensure that tree species diversity is the only factor influencing productivity, stands were identified that were similar in growth and ecological factors but different in their proportion of Masson pine (*Pinus massoniana*). The general information of the plots is shown in Table 1. The vegetation was a mix of middle subtropical to northern tropical deciduous to coniferous forests, composed mainly of pure Masson pine, scattered with broadleaf *Phyllostachys* bamboo. There were a few tree species, the most commonly identified as *Euscaphis japonica*, *Vitex negundo*, *Dalbergia hupeana*, *Lindera glauca*, and *Pistacia chinensis*. Less frequently identified were *Liquidambar formosana*, *Platycarya strobilacea*, *Quercus acutissima*, *Smilax china*, and *Mallotus tenuifolius*. The stands selected had been planted, were not irrigated, and had not been disturbed for more than 30 years. Broadleaf species invasion occurred naturally.

Table 1. Characteristics of the 15 stands.

Sample code	Mixed ratio (%)*	Altitude (m)	Slope	Inclination (°)	Slope position	Density (tree/ha)		Mean height (m)		Mean trunk diameter (cm)	
						Pinus massoniana	Broad-leaved tree	*Pinus massoniana*	Broad-leaved tree	*Pinus massoniana*	Broad-leaved tree
1	<20	163	South	23	Upside	150	450	8.3	7.6	15.9	15.2
2	<20	70	South	10	Middle	75	775	7.0	7.3	17.5	15.1
3	<20	161	East	18	Underside	175	700	5.9	7.7	11.9	16.4
4	20-40	62	Northwest	23	Middle	450	550	8.3	8.3	13.4	16.5
5	20-40	90	West	29	Underside	375	775	9.0	7.5	14.1	14.0
6	20-40	162	South	11	Middle	225	575	8.6	7.1	17.4	14.7
7	40-60	217	South	27	Upside	275	175	8.7	8.3	15.7	17.8
8	40-60	102	South	24	Middle	200	500	9.3	9.1	19.7	15.5
9	40-60	170	South	21	Upside	425	400	8.5	7.3	16.3	16.0
10	60-80	96	East	18	Underside	625	325	8.0	6.9	14.4	11.4
11	60-80	68	Southwest	20	Underside	600	350	9.8	7.1	13.9	12.7
12	60-80	156	Southeast	15	Middle	950	150	6.6	7.0	11.7	16.7
13	>80	217	Southwest	21	Upside	700	125	9.1	5.8	15.6	13.8
14	>80	157	South	26	Middle	1425	100	8.7	5.7	13.9	10.4
15	>80	80	South	20	Underside	1175	50	7.1	7.3	13.2	16.0

*The actual percentages of Masson pine were 17.2, 35.6, 45.6, 75.2, 92.3% in these stands.

Sampling design

Fifteen plots, situated away from the forest edge, with five different proportions of Masson pine in a mixed forest, were selected for analyzing the proportions of different species in the mixed woods effect on production of biomass. Except for the mixed proportions, the woodland habitat factors of these plots (including altitude, aspect, slope, slope position, soil properties, light, heat, and moisture) were basically the same, as was the stand age. Values of the mixed proportions of Masson pine in the 15 forest plots were measured based on surveys of three 20 x 20 m standard areas of each plot, and were then classified into five levels, namely, <20%, 20 to 40%, 40 to 60%, 60 to 80%, and >80%, which were marked as I, II, III, IV, and V, respectively, for convenience. The actual average value of proportions of Masson pine for each level was 17.2, 35.6, 45.6, 75.2, and 92.3%, respectively.

Data collection

From the end of July to early August 2009, in each selected mixed stand, one 0.04 ha circular sample plot was established for investigating biomass, understory vegetation, and understory plant diversity. To estimate the biomass in each sample plot, the following features were measured and examined in each plot.

Above-ground arboreal biomass

The diameter at breast height (DBH) and the height of the individual tree, in three 20 x 20 m standard areas of each plot, were measured. A standard tree of each plot was then chosen, based on information collected from the average value of DBH and tree height of the whole plot. Three standard trees were cut down and divided into sections of 1 m and weighed fresh to obtain weights of the trunk, limbs, branches, leaves, and bark, separately. In a laboratory, samples were dried at a temperature of 70°C to a constant mass to determine the oven-dried biomass and were then weighed to the nearest 0.01 g. The water content and dry weight were calculated accordingly. Finally, the biomass was calculated using the average sample tree method.

Above-ground biomass of understory vegetation

In each sample plot, five 2 x 2 m subplots were randomly allocated to determine the understory vegetation biomass. The above-ground biomass of all shrubs and herbs was clipped from each of the five randomly located 4-m^2 subplots. The understory vegetation within the plots was investigated. The shrubs were separated from the herbs, and each group was weighed fresh. These samples were then oven-dried at 70°C to a constant mass to determine the oven-dried biomass, weighed to the nearest 0.01 g.

$$Wu = \sum Wui / (A \times N) \times 10{,}000$$

where Wu is the biomass per hectare, ∑Wui is the cumulative sum of the biomass, A is the area of sample plots, and N is the number of sample plots.

Fine root biomass

From March 2008 to September 2009, in each sample area, 20 points were randomly selected along a zigzag. At each point, soil samples were collected from three layers (0 to 10, 10 to 20, and 20 to 30 cm) using a soil drill of 6.8 mm inner diameter. A total of 270 samples were collected from 15 sample stands. The soil samples were numbered, put into plastic bags, and taken to a laboratory. There, they were soaked in water, and then washed under flowing water over a 0.5-mm diameter soil screen. The cleaned roots were stored in bags and dried at 70°C for testing. The fine roots (<2 mm in diameter) were sorted.

Statistical analysis

To observe the relationships in biomasses across stand development, the field data for the above-ground tree, understory, and fine root, biomass, and total biomass of the mixed forest were calculated for each sample site by summing the samples for that site. The mean biomass was calculated for each of the mixed forest biomasses for each developmental stage, allowing observation of how the biomass varied for each stand. The *t*-test was used to test the fine root biomass. We used the following model to represent the understory vegetation biomass:

$$Wu = \sum Wui / (A \times N) \times 10^4$$

where *Wu* is the biomass per hectare, ∑*Wui* is the cumulative sum of the biomass, *A* is the area of quadrates, and *N* is the number of quadrates.

The fine root standing biomass estimates were calculated as follows:

$$R\ (t \cdot hm^{-2}) = \text{Average weight of soil core fine root} \times 10^2 / [\pi \cdot (D/2)^2]$$

where *R* is the fine root reserves, *A* is the average weight of soil core fine root, and *D* is the diameter of the soil drill.

RESULTS

Above-ground tree biomass

The above-ground tree biomass constitutes the largest portion of total biomass in these stands. Among the stands, when the proportion of Masson pine gradually increased from <20 to >80%, the above-ground biomasses displayed an increase-decrease trend, as shown in Table 2. The order of the above-ground biomasses was III > II > IV > V > I. The difference between stands III and I was significant ($P < 0.01$). The above-ground arboreal biomass in stand III was 281 Mg/ha, whereas it was 217 Mg/ha in stand I.

Table 2. Total above-ground biomass in the Masson pine mixed forest.

Mixed ratio (%)	Tree layer biomass (t/ha)	Understory biomass (t/ha)	Above-ground biomass (t/ha)
0-20%	216.663	1.39	218.053
21-40%	273.946	1.47	275.416
41-60%	281.583	1.52	283.103
61-80%	246.485	1.19	247.675
81-100%	232.657	1.13	233.787

Understory biomasses

The understory biomasses differed with changes in the proportion of Masson pine (Table 2). The order of the shrub biomasses was III > II > I > V > IV. Among these, the difference between stands III and IV was significant (0.38 t/hm^2, $P < 0.01$), and with the lowest being 0.98 t/hm^2 and the highest being 1.36 t/hm^2. The order of biomasses of the herb layer was IV > III > II > V > I. Among these, the herb biomasses were 0.21 and 0.07 t/hm^2, respectively, in stands IV and I. The former was 3 times more than the latter. The difference between these two proportions was significant ($P < 0.01$). Stand III had the largest arboreal biomass but not the largest herb biomass. Stand I had the lowest herb biomass but relatively large arboreal biomass. These results indicate that trees influence the availability of light to herbs, influencing the development of the herb layer.

Above-ground total biomass

The above-ground total biomasses increased in the order of stand types III > II > IV > V > I (Table 2). The difference between stands III and I was significant (65.05 t/hm^2, $P < 0.01$), with their above-ground total biomasses being 283.103 and 218.053 t/hm^2, respectively. The tree biomass is the major layer of those above ground. The differences in the understory biomasses between the different stands were small. The arboreal and understory biomasses in stand III were the largest. Therefore, the above-ground biomass of stand III was also the largest.

Fine root biomasses

Fine root biomasses displayed a declining trend as the depth of soil increased (Figure 1). Most of the fine root biomass was within the 0 to 10 cm layer. Within the 30 cm depth, the highest fine root biomass was found in the top 10 cm of soil, being 49.4%. In stand III, soil strata 0 to 10 and 10 to 20 cm had the largest fine root biomass. In stand II, the 20 to 30 cm soil stratum had the largest fine root biomass. The difference between stands III and II was significant ($P < 0.01$). Stand comparison revealed that the fine root biomass was the largest in stand III, reaching 1.799 t/hm^2, whereas it was the least in stand II, being only 1.581 t/hm^2. The order of fine root biomasses was III > I > IV > V > II. In each stand type, the fine root biomass in the 0 to 10 cm soil stratum was significantly different from that in the other two strata. In stand III, the fine root biomasses within the 10 to 20 cm soil stratum had a significant difference. The fine root biomasses in stand II within the 20 to 30 cm soil layer were significantly different. The total fine root biomasses were significantly different between stands III and II.

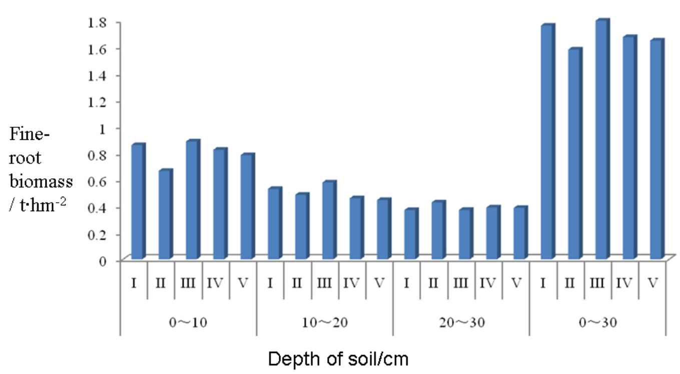

Figure 1. Fine-root biomass distribution in 0-30-cm soil layer of mixed forest (I, II, III, IV, and V stands for 5 different mixed ratios of Masson pine in sampling plots).

The *t*-testing of the independent samples revealed that stand III, in comparison with stands I, II, III, and V, had significant differences within the 0 to 10 cm layer (Table 3). In stand III, the results of the *t*-test showed a significant difference from the other stands, within the 10 to 20 cm layer (Table 4). In the 20 to 30 cm layer, stand III also had significant differences in comparison with stands I, II, III, and V, (Table 5).

Table 3. Fine-root biomass paired-sample *t*-test in 0-10-cm soil layer of mixed forest.

	0-20%	21-40%	41-60%	61-80%
0-20%				
21-40%	-1.507 (0.150)			
41-60%	2.334 (0.032)	3.498 (0.003)		
61-80%	-3.740 (0.002)	-3.273 (0.004)	4.108 (0.001)	
81-100%	-1.403 (0.179)	-2.057 (0.050)	3.462 (0.003)	3.345 (0.004)

Numbers in parentheses indicate the P value.

Table 4. Fine-root biomass paired-sample *t*-test in 10-20-cm soil layer of mixed forest.

	0-20%	21-40%	41-60%	61-80%
0-20%				
21-40%	-0.102 (0.920)			
41-60%	1.261 (0.224)	2.119 (0.049)		
61-80%	-2.779 (0.013)	-2.878 (0.010)	2.456 (0.025)	
81-100%	0.058 (0.954)	0.230 (0.821)	2.252 (0.038)	3.345 (0.004)

Numbers in parentheses indicate the P value.

Table 5. Fine-root biomass paired-samples *t*-test in 20-30-cm soil layer of mixed forest.

	0-20%	21-40%	41-60%	61-80%
0-20%				
21-40%	-0.610 (0.551)			
41-60%	0.939 (0.361)	3.115 (0.006)		
61-80%	0.442 (0.678)	0.332 (0.774)	2.267 (0.037)	
81-100%	-0.551 (0.589)	-0.159 (0.876)	2.509 (0.023)	-0.421 (0.037)

Numbers in parentheses indicate the P value.

DISCUSSION

Among the five Masson pine stands, the order of above-ground arboreal biomasses was (by proportion) III > II > IV > V > I. Among these, the above-ground arboreal biomass in stands with 45.6% Masson pine was the largest, whereas that in stands with 92.3% Masson pine was the smallest. The understory biomass was largely composed of the shrub layer. Although herbs occupied much of the surface area and were abundant, their biomass was the smallest portion. As the proportion of ground surface area of Masson pine increased, the understory biomass first increased and then decreased (the maximal shrub biomass was 1.36 t/hm^2 measured in stands with 45.6% Masson pine). The fine roots of Masson pine and broadleaf trees were mainly found in the 0 to 10 cm soil layer. The deeper the soil was, the fewer fine roots were found. The largest fine root biomass was measured in stands with 45.6% Masson pine, whereas the lowest fine root biomass was identified in stands with 35.6% Masson pine. The differences between the two stands were significant.

Stands with 45.6% Masson pine had the largest above-ground tree, understory, and fine root biomasses. This proportion of Masson pine in the stand positively influences the growth of stands and is an important factor influencing biomass creation.

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