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Aboveground biomass of three conifers in the Qianyanzhou plantation, Jiangxi Province, China

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Abstract Regressive models of the aboveground biomass for three conifers in subtropical China—slash pine (*Pinus elliottii*), Masson pine (*P. massoniana*) and Chinese fir (*Cunninghamia lanceolata*)—were established. Regression analysis of leaf biomass and total biomass of each branch against branch diameter (d), branch length (L), d^3 and d^2L was conducted with functions of linear, power and exponent. A power law equation with a single parameter (d) was proved to be better than the rest for Masson pine and Chinese fir, and a linear equation with parameter (d^3) is better for slash pine. The canopy biomass was derived by adopting the regression equations to all branches of each individual tree. These kinds of equations were also used to fit the relationship between total tree biomass, branch biomass, foliage biomass and tree diameter at breast height (D), tree height (H), D^3 and D^2H , respectively. D^2H was found to be the best parameter for estimating total biomass. However, for foliage biomass and branch biomass, both parameters and equation forms showed some differences among species. Correlations were highly significant ($P < 0.001$) for foliage biomass, branch biomass and total biomass, among which the equation of the total biomass was the highest. With these equations, the aboveground biomass of Masson pine forest, slash pine forest and Chinese fir forest were estimated, in addition to the allocation of aboveground biomass. The aboveground biomass of Masson pine forest, slash pine forest

and Chinese fir forest was 83.6, 72.1 and 59 t/hm² respectively, and the stem biomass was more than the foliage biomass and the branch biomass. The under-ground biomass of these three forests which estimated with others' research were 10.44, 9.42 and 11.48 t/hm², and the amount of carbon-fixed were 47.94, 45.14 and 37.52 t/hm², respectively.

Keywords *Pinus massoniana*, *Pinus elliottii*, *Cunninghamia lanceolata*, biomass, allometric equations

1 Introduction

Plant biomass is not only the foundation for studying ecosystem structure and function, but also the basic data for studying the carbon fixation capacity of ecosystem and forecasting the global change trends. Among the earth's major terrestrial biomes, forests control 80% of aboveground carbon storage and 40% of underground carbon storage (Dixon et al., 1994). Forests have the most important effect on biogeochemical cycles as well (Jiang, 1996). Previous studies also showed that most of carbon storage is in tropical and subtropical areas (Watson and Verardo, 2000). Masson pine (*Pinus massoniana*) and Chinese fir (*Cunninghamia lanceolata*) are major tree species for afforestation in the subtropical area of China (Li, 1996), and slash pine was also widely cultivated in the south of China since it was introduced in the 1980s (Ren, 1997). So studying the growth law and biomass allocation of these three species is very important for estimating the total biomass and carbon fixation capacity of subtropical plantation ecosystems.

There are two approaches often used to estimate biomass of terrestrial biomes, overall. One is sampling and harvesting in plots directly, and the other is estimating by other data (i.e. satellite imagery data) along with survey data indirectly (Zhou and Wang, 2003). Biomass of trees in forest ecosystems can be obtained by mean tree method or class mean sample tree method (Dong, 1997; Yu, 2003). The latter is often used to

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develop allometric equations. In previous studies, a lot of allometric equations for masson pine, slash pine and Chinese fir were established to estimate aboveground biomass in China, such as Feng et al. (1982), Chen et al. (1984), Ma (1989) and Tian et al. (1998). However, if the existing equations are directly used in another forest, error will occur for different trunk densities.

In our study, Masson pine, slash pine and Chinese fir in Qianyanzhou Station (Jiangxi Province, China) were sampled and allometric equations of the three species were established. We aimed: 1) to find out the best parameter and function type for establishing allometric equations; 2) to reduce destruction in forests, focusing on how can we cut as less trees as possible to carry out our study without depressing the accuracy; 3) to find out how the biomass is allocated in Qianyanzhou forests; and 4) to predict the carbon density of Qianyanzhou forests after 20 years of restoration on the red soil hilly region.

2 Study area and methods

2.1 General information

We carried out our study in Qianyanzhou Experimental Station, Chinese Academy of Sciences, which is located at 26°44'48''N, 115°04'13''E in Jiangxi Province of China. The study area is typically a red soil hilly region. The dominant species in the plantation are slash pine, Masson pine and Chinese fir, which were planted mainly in 1984 (Cheng and Li, 1998). Before the trees were planted, the station area was almost a barren hill and grass slope, and trees could not be restored naturally for the harvesting of local villagers.

The climate type in the study area is a subtropical monsoon climate. In the spring of 2002, some slash pines were pressed down by heavy snow. These trees were investigated in our study. There is a Shixi Forest Farm near the station, about 5 km, in which a lot of Chinese fir were cut down in 2001, with part of each branch still on trunks. Part of these trees was investigated as well.

Plantation in Qianyanzhou Station was investigated according to forest types from July to September in 2003. Forest types were named with dominant species. Masson pine forest and slash pine forest were investigated in two 20 m × 20 m plots separately, Chinese fir forest was investigated in one 20 m × 20 m plot and one 10 m × 10 m plot, and mixed-conifer forest (Masson pine and slash pine mainly) in four 10 m × 10 m plots. Each plot was surveyed according to tree layer, shrub layer and herb layer. Species, tree height, diameter at breast height (DBH), crown diameter and coverage of tree layer were measured and noted in our study. The species' composition for the four forest types is listed in Table 1.

2.2 Methods

In our study, forest biomass was obtained with allometric equations and tally data. Allometric equations were established by developing the regression relationship between biomass and some stand description factor, such as tree height (H), DBH (D), D^3 and D^2H . The aboveground biomass of each individual tree was divided into three parts: leaf biomass, branch (without leaf) biomass and trunk biomass. The biomass of each part was estimated first, and aboveground biomass of individual tree was derived with the sum of the three.

Leaf biomass and branch biomass of each branch are related to branch description factors such as branch basal diameter (d) and branch length (L). If regression equations for each branch were developed, and the description factors of all the branches on one tree measured, leaf biomass and branch biomass of each individual tree can be derived. In our study, d , L , d^3 and d^2L were selected to fit the regression equations, and the equations with the highest correlation coefficient were selected to estimate leaf biomass and branch biomass.

Trunk biomass was estimated with timber volume and trunk density. In previous studies, a lot of allometric equations and volume equations for Masson pine, slash pine and Chinese fir were established as mentioned earlier. These equations cannot be used for the Qianyanzhou plantation directly, so we cut some trees to correct these equations. Trunk biomass was then estimated with corrected volume equations and measured trunk density.

In our study, 14 Masson pines, four slash pines and five Chinese firs in different diameters were logged in experimental area, and most of the stand description factors, such as DBH , basal area, tree height, crown diameter, dead branch weight, trunk weight, strobile weight and diameter of all first class branches were recorded. Moreover, 17 Chinese firs in the Shixi Forest Farm and 14 slash pines pressed down by the snow in the station were also measured. Meanwhile, some normal first class branches were selected to establish the regression equations, with basal diameter, branch length, old leaf weight, new leaf weight and branch weight measured. Water content of old leaves, new leaves, branches, barks, xylems, strobiles and density of xylems and barks were also measured. Function types used to fit the regression equations are linear ($Y = a + bX$), power ($Y = aX^b$) and exponential ($Y = ae^{bX}$) function.

3 Results and analysis

3.1 Biomass models of branch

Seventy-two equations were established for determining the regression relationship between biomass (leaf weight

Table 1 Species composition of different forest types

species	masson pine forest			slash pine forest			Chinese fir forest			mixed-conifer forest			DBH/ cm				
	density/ stems·hm ⁻²	DBH/ cm	BA/m ² · hm ⁻²	%BA/% stems·hm ⁻²	density/ stems·hm ⁻²	DBH/ cm	BA/ m ² ·hm ⁻²	%BA/% stems·hm ⁻²	density/ stems·hm ⁻²	DBH/ cm	BA/m ² · hm ⁻²	%BA/% stems·hm ⁻²					
<i>Pinus massoniana</i>	1850	13.7	28.92	83.74	88	14.6	1.52	4.32	—	—	—	—	1300	15.4	16.92	47.66	14.2
<i>Pinus elliotii</i>	288	12.5	3.92	11.37	1475	16.8	33.63	95.56	280	12.9	7.29	21.79	975	14.8	17.67	49.77	15.6
<i>Cunninghamia lanceolata</i>	—	—	—	—	—	—	—	—	3420	9.2	26.01	77.79	25	19.4	0.74	2.09	9.2
<i>Eurya muricata</i>	412	1.9	0.14	0.41	12	1.6	< 0.01	0.01	20	1.9	0.01	0.02	—	—	—	—	1.9
<i>Campotheca acuminata</i>	38	8.0	0.33	0.95	—	—	—	—	—	—	—	—	—	—	—	—	8.0
<i>Cinnamomum camphora</i>	38	1.9	0.01	0.03	—	—	—	—	—	—	—	—	—	—	—	—	1.9
<i>Loropetalum chinense</i>	350	1.9	0.10	0.29	62	2.2	0.02	0.07	—	—	—	—	—	—	—	—	1.9
<i>Adiantum boeckiana</i>	150	2.2	0.05	0.13	25	1.8	0.01	0.02	—	—	—	—	25	2.9	0.02	0.04	2.2
<i>Rhus chinensis</i>	88	1.9	0.02	0.06	—	—	—	—	—	—	—	—	—	—	—	—	1.9
<i>Melia azedarach</i>	88	11.7	0.99	2.86	—	—	—	—	—	—	—	—	—	—	—	—	11.7
<i>Vaccinium bracteatum</i>	50	1.5	0.01	0.03	12	1.9	< 0.01	0.01	120	1.6	0.03	0.08	—	—	—	—	1.6
<i>Photinia prunifolia</i>	25	1.8	0.01	0.02	—	—	—	—	—	—	—	—	—	—	—	—	1.8
<i>Styrax japonicus</i>	25	1.4	0.01	0.01	—	—	—	—	—	—	—	—	—	—	—	—	1.4
<i>Aralia elata</i>	25	1.1	< 0.01	0.01	—	—	—	—	—	—	—	—	—	—	—	—	1.1
<i>Chaenomeles speciosa</i>	12	2.6	0.02	0.07	—	—	—	—	—	—	—	—	—	—	—	—	2.5
<i>Alniphyllum fortunei</i>	—	—	—	—	12	2.5	0.01	0.02	40	2.5	0.02	0.06	—	—	—	—	2.5
<i>Aleurites fordii</i>	—	—	—	—	—	—	—	—	80	3.2	0.08	0.25	—	—	—	—	3.2
<i>Liquidambar formosana</i>	—	—	—	—	—	—	—	—	—	—	—	—	100	3.2	0.08	0.23	3.2
<i>Schinus molle</i>	—	—	—	—	—	—	—	—	—	—	—	—	100	2.4	0.04	0.13	2.4
<i>Litsea cubeba</i>	—	—	—	—	—	—	—	—	—	—	—	—	25	3.8	0.03	0.08	3.8

DBH: Diameter at breast height; BA: Basal area; %BA: Percentage of BA for each species; —: absence.

(*LW*) and total weight (*BW*) of each branch) and branch description factors (branch basal diameter (*d*), branch length (*L*), d^3 and d^2L) with linear, power and exponential functions for Masson pine, slash pine and Chinese fir, from which the 24 equations with highest correlation coefficient for each independent variable were selected and listed in Table 2. Although all the equations can pass the significance test ($P < 0.001$), the correlation coefficients were variable. For branches of all the three species, equations for total biomass had higher correlation coefficients than those for leaf biomass. Similar situation was also found when allometric equations of leaf biomass and total biomass were established for individual trees later. The conclusion was consistent with others' studies (Ma, 1989; Wang et al., 1996). The reason might be: firstly, the leaf biomass of each branch was related to branch position and tree height, however, these factors had less effect on the total biomass of each branch; secondly, leaf biomass was strongly affected by micro-environmental conditions, such as density of crown.

The correlation coefficients of biomass equations for the different function types were variable. However, most of the equations with the highest correlation coefficient were power law equations and only a small number of them were linear equations, and none was exponential. This indicated that the power function was the best function type for fitting the relationship between biomass and certain description factor.

The correlation coefficients of biomass equations for different independent variables were also variable. Correlation coefficients of regression equations with the independent variable (*d*) were higher than those with independent variable (*L*). Equations with the independent variable (d^2L) had lower correlation coefficient than those with independent variable (d^3) except for the

equation for Masson pine branch biomass. When the correlation can be described very well with one parameter, the added parameter might decrease the accuracy of the description (Neter et al, 1974; Bruce et al, 1999).

All equations with independent variable d^3 had much higher correlation coefficients, but the function types for three species were not the same. The function type for slash pine was linear function, those for Masson pine and Chinese fir were power function. It is easy to consider that when the basal diameter of branch is 0, the biomass must be 0. So we set the intercept in linear equations equal to 0 for slash pine and fit the equations again and found that the correlation coefficients were still higher than those for the other two kinds of equations. Taking the correlation coefficient and parameter numbers into account, six equations with independent variable d^3 were selected (Table 3) to estimate leaf biomasses and branch biomasses of 14 slash pines pressed down by snow, 17 Chinese firs measured in Shixi Forest Farm (mentioned in Study area and methods) and nine sampled Masson pines that were not measured for leaf biomass and branch biomass.

3.2 Biomass models of trunk

The timber dry matter density of Masson pine, slash pine and Chinese fir were sampled and measured, which were 346.6, 298.9 and 298.8 kg/m³, and dry matter ratio (dry matter/fresh matter) of the timber for the three species were 34.6%, 29.4% and 37.1%, respectively. Volume (V_T) of sample trees in the plantation (five Masson pines, four slash pines and five Chinese firs) was calculated with trunk fresh weight, dry matter ratio and timber dry matter density. The volume (V) of these trees was also calculated with volume equations (listed in Table 4)

Table 2 Regressive parameters of branch biomass and leaf biomass models

		<i>P. massoniana</i>		<i>P. elliotii</i>		<i>C. lanceolata</i>	
		<i>LW</i>	<i>BW</i>	<i>LW</i>	<i>BW</i>	<i>LW</i>	<i>BW</i>
<i>d/mm</i>	r^2	0.586	0.936	0.543	0.873	0.809	0.966
	<i>a</i>	0.2295	0.0694	0.553	0.3358	0.0488	0.0392
	<i>b</i>	1.7955	2.7232	1.7203	2.2375	2.4709	2.8934
<i>L/cm</i>	r^2	0.364	0.846	0.310	0.655	0.659	0.876
	<i>a</i>	0.0904	0.0026	0.0945	0.0103	0.0208	0.0090
	<i>b</i>	1.2015	2.1989	1.3116	1.9565	1.6591	2.0494
d^3/cm^3	r^2	0.586	0.936	0.543	0.873	0.912*	0.971*
	<i>a</i>	14.3322	36.6773	29.0430	58.0092	15.8940*	7.0028*
	<i>b</i>	0.5985	0.9077	0.5734	0.7458	7.9861*	27.4995*
d^2L/cm^3	r^2	0.521	0.945	0.488	0.848	0.878*	0.955*
	<i>a</i>	1.3562	0.7405	2.3989	1.9388	16.5527*	5.7904*
	<i>b</i>	0.5456	0.8816	0.5619	0.7601	0.1080*	0.3756*
Range		4.5 mm $\leq d \leq$ 42 mm 27 cm $\leq L \leq$ 520 cm		3.5 mm $\leq d \leq$ 29.8 mm 30 cm $\leq L \leq$ 256 cm		5.2 mm $\leq d \leq$ 53 mm 23 cm $\leq L \leq$ 372 cm	
Sample size		156		156		178	

LW: leaf dry weight (g); *BW*: branch dry weight (g); *d*: basal diameter; *L*: branch length. The same below.

$F_{0.001}(1,176) < F_{0.001}(1,154) < F_{0.001}(1,120) = 11.38$. * indicates linear function; others are all power function.

Table 3 Parameters of regressive equations for branches with higher correlation coefficients

species	items	equations	F	r^2	sample sizes	range/cm
<i>P. massoniana</i>	LW	$LW = 14.3322(d^B)^{0.5985}$	217.69	0.586	156	$0.45 \leq d \leq 4.2$
	BW	$BW = 36.6773(d^B)^{0.9077}$	2253.82	0.936		
<i>C. lanceolata</i>	LW	$LW = 29.0430(d^B)^{0.5734}$	209.32	0.543	178	$0.35 \leq d \leq 2.98$
	BW	$BW = 58.0092(d^B)^{0.7458}$	1211.46	0.873		
<i>P. elliotii</i>	LW	$LW = 8.2725d^B$	1489.50	0.883	156	$0.52 \leq d \leq 5.3$
	BW	$BW = 27.6260d^B$	5119.97	0.966		

Table 4 Equations for timber volume

species	cited equation	DBH/cm	corrected equation	r^2	F
<i>P. massoniana</i>	$V = 0.00006228789D^{1.849839}H^{0.9843411}$ (Ye et al., 1996)	7.1–5.1	$V_t = 1.3608V^{1.1338}$ i.e.: $V_t = 2.32 \times 10^{-5}D^{2.0974}H^{1.116}$	0.9964	831.70
<i>P. elliotii</i>	$V = 0.000059398D^{2.159967}H^{0.6678276}$ (Zheng et al., 1999)	5.6–31.3	$V_t = 0.8652V^{1.0312}$ i.e.: $V_t = 3.7934 \times 10^{-5}D^{2.2274}H^{0.6887}$	0.9972	710.11
<i>C. lanceolata</i>	$V = 40.00008371201D^{1.84207309}H^{0.90309687}$ (Duan et al., 1994)	6–30	$V_t = 0.962V^{1.0457}$ i.e.: $V_t = 5.2437 \times 10^{-5}D^{1.9263}H^{0.9444}$	0.9969	979.03

Unit: V_t , V (m^3), D (cm), H (m). $F_{0.005}(1,2) = 198.5$, $F_{0.005}(1,3) = 55.6$, $F_{0.001}(1,2) = 998.5$, $F_{0.001}(1,3) = 167$.

established by others in previous studies. The comparison showed that V was larger than V_t (8.3% for Masson pine, 22.2% for slash pine and 15.2% for Chinese fir) for all three species. Linear, power and exponential functions were used to develop the correlation relationship between V_t and V . F -test showed that the fitness was significant for all the equations, and the correlation coefficient of power function was higher than those of the other two. So, the equations corrected with power function (see Table 4) were selected to calculate volume of Chinese firs in Shixi Forest Farm and slash pines pressed down by snow. Then the trunk biomass was estimated with trunk volume and density.

3.3 Biomass models for individual trees

Four parameters, D , H , D^3 and D^2H , were selected to fit the regression relationship between biomass (foliage

biomass, branch biomass, trunk biomass and total aboveground biomass) and description factors for individual trees. And 144 equations were obtained, from which the 12 equations with the highest correlation coefficient were selected and listed in Table 5. The order of the correlation coefficients for the organs was: trunk biomass > total aboveground biomass > foliage biomass > branch biomass, and the fitting effect for total biomass was better than those for the foliage biomass and branch biomass, regardless of the parameter used. The reason why the equations for trunk biomass had the highest correlation coefficient might be that the trunk biomass was calculated with corrected timber volume equations and trunk density directly.

Results also showed that for certain species, the function type and independent variable of equations with the highest correlation coefficient for branch biomass and foliage biomass were almost the same.

Table 5 Parameters of equations for individual trees with the highest regressive coefficients

species	items	variables	equation types	r^2	F	P	a	b	range
<i>P. massoniana</i> (14)	FB	D^2H	Exponential	0.903	112	<0.001	364.083	0.0008	$5.8 \text{ cm} \leq D \leq 16.6 \text{ cm}$; $9 \text{ m} \leq H \leq 12 \text{ m}$
	BB	D	Exponential	0.865	77	<0.001	182.72	0.2736	
	TB	D^2H	Power	0.999	12898	<0.001	9.0328	1.0549	
<i>P. elliotii</i> (19)	AB	D^2H	Power	0.988	1007	<0.001	7.1763	1.1328	$7.6 \text{ cm} \leq D \leq 29.7 \text{ cm}$; $8.8 \text{ m} \leq H \leq 21.8 \text{ m}$
	FB	D^2H	Power	0.758	53	<0.001	5.2255	0.8529	
	BB	D^2H	Power	0.733	47	<0.001	18.5862	0.7945	
<i>C. lanceolata</i> (22)	TB	D^2H	Power	0.998	7631	<0.001	8.6613	1.0178	$9.6 \text{ cm} \leq D \leq 25.9 \text{ cm}$; $8.4 \text{ m} \leq H \leq 14.5 \text{ m}$
	AB	D^2H	Linear	0.975	654	<0.001	2852.04	14.6382	
	FB	D	Power	0.788	74	<0.001	5.2619	2.3027	
	BB	D	Power	0.764	65	<0.001	1.6225	2.9235	
	TB	D^2H	Power	0.999	18016	<0.001	15.5054	0.9583	
	AB	D^2H	Power	0.985	1318	<0.001	21.0578	0.9476	

FB: foliage biomass; BB: branch biomass; TB: trunk biomass; AB: aboveground biomass. $F_{0.001}(1, 12) = 18.64$, $F_{0.001}(1, 17) = 15.72$, $F_{0.001}(1, 20) = 14.82$. The numbers in brackets are sample sizes.

Table 6 Power law equations with D or D^2H as independent variable

species	items	D				D^2H			
		r^2	F	a	b	r^2	F	a	b
<i>P. massoniana</i> (14)	FB	0.874	83.51	6.9727	2.1973	0.866	77.35	1.0525	0.9956
	BB	0.854	70.06	4.7430	2.8422	0.853	69.43	0.3953	1.2933
	TB	0.991	1299.92	70.3299	2.3072	0.999	12898.3	9.0328	1.0549
	AB	0.983	709.13	64.4026	2.4817	0.988	1007.34	7.1763	1.1328
<i>P. elliotii</i> (19)	FB	0.735	47.24	12.0741	2.1515	0.758	53.35	5.2255	0.8529
	BB	0.713	42.17	40.1892	2.0074	0.733	46.57	18.5862	0.7945
	TB	0.991	1832.43	21.6574	2.5980	0.998	7631.12	8.6613	1.0178
	AB	0.959	395.79	49.5799	2.4616	0.970	554.13	20.4309	0.9667
<i>C. lanceolata</i> (22)	FB	0.788	74.40	5.2619	2.3027	0.753	60.87	3.0101	0.8446
	BB	0.764	64.69	1.6225	2.9235	0.727	53.28	0.8104	1.0705
	TB	0.975	768.26	37.9323	2.5221	0.999	18016.20	15.5054	0.9583
	AB	0.976	814.35	48.2541	2.5133	0.985	1318.09	21.0578	0.9476

$F_{0.001}(1,12) = 18.64$, $F_{0.001}(1,17) = 15.72$, $F_{0.001}(1,20) = 14.82$.

Masson pine, however, showed a little difference. The coefficient of determination r^2 of exponential equations for foliage biomass with independent variable D was 0.899, and the r^2 of exponential equations for branch biomass with independent variable D^2H was 0.859. These values were only a little less than those listed in Table 5 (0.903 and 0.865, respectively). For different species, however, different functions and independent variables should be used to get the best fitting effect for foliage biomass and branch biomass. The reason might be that the foliage biomass and branch biomass of each species was controlled by its own physiological characteristics such as crown structure and branch/leaf growth law.

Most of the equations with the highest correlation coefficient were power law equation, and independent variables of these equations were D and D^2H . All power law equations with independent variables D and D^2H were listed in Table 6. F value and correlation coefficient of these equations were rather large, and all of them can pass F -test, so all of them can be used to estimate the biomass of biome.

3.4 Aboveground biomass of dominant species and its allocation

Taking equation forms and reliability of the result into account, the power law equations with independent variable D^2H were selected to estimate each organ biomass and aboveground biomass of arbor layer with tally data in Qianyanzhou Station. The plantation in Qianyanzhou Station was dominated by Masson pine, slash pine and Chinese fir. $DBHs$ of other species were smaller than the dominant species and had only quite a little proportion in total basal area (percentage for Masson pine forest is 4.89%, slash pine forest 0.12%, Chinese fir forest 0.42%, mixed coniferous forest 0.48%) (Table 1). When estimating aboveground biomass, the contribution of other species can be ignored.

The sequence of aboveground biomasses: Masson pine forest (83.6 t/hm^2) > mixed coniferous forest (75.2 t/hm^2) > slash pine forest (72.1 t/hm^2) > Chinese fir forest (59 t/hm^2), and the sequences of branch biomass and trunk biomass were the same as the aboveground

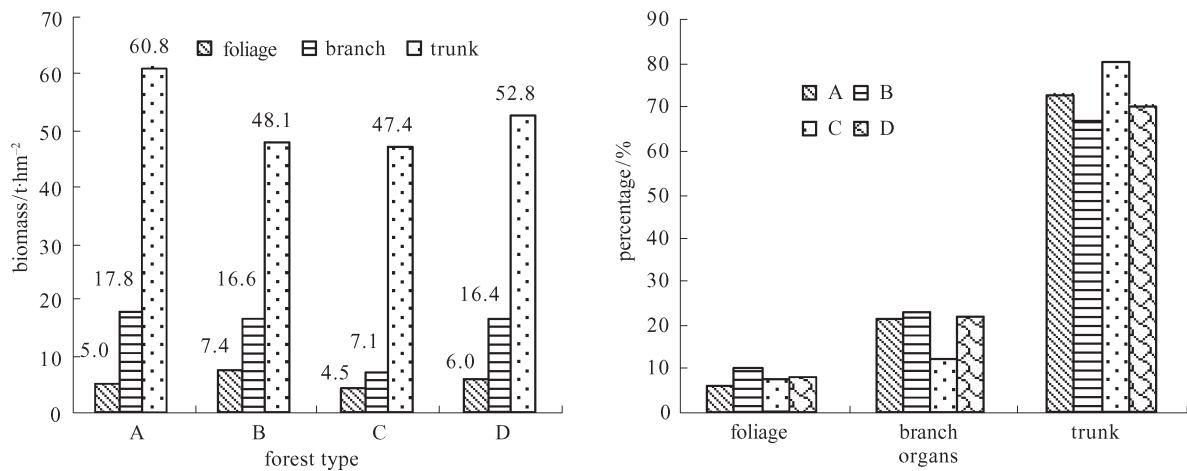


Fig. 1 Allocation of biomass in organs in different forest types. A: Masson pine forest, B: slash pine forest, C: Chinese fir forest, D: mixed coniferous forest.

biomass. For the foliage biomass, slash pine forest was higher than the other three, while the Chinese fir forest had the least foliage biomass of the four. Among all the three organs (foliage, branch and trunk), trunk covered the largest proportion of aboveground biomass, which controlled more than 65% of the aboveground biomass. Branch controlled 11% to 23% of aboveground biomass and foliage had the least proportion of the three, which was below 10% for all forest types.

The mean *DBH* of dominant species, reserve density and density of trunk had direct effect on biome aboveground biomass. Meanwhile, the mean *DBH* and reserve density interacted. The mean *DBH* of the Chinese fir forest was far less than that of the Masson pine forest, slash pine forest and mixed coniferous forest. Since all the trees were planted nearly at the same time, the reserve density (Table 1) may be the key factor affecting the growth of each individual (Fang, 2004) tree. The mean *DBH* of the Masson pine forest was smaller than that of the slash pine forest, but its aboveground biomass was larger than that of the slash pine forest. One of the reasons was the influence of different trunk density.

The proportion of the organ biomass in the aboveground biomass was also different for the different forest types. In the proportion of foliage biomass, the slash pine forest had the largest proportion, while the Masson pine had the least. The growth law of foliage was mostly controlled by biological property. The Chinese fir forest had the least proportion of branch biomass, but had the highest proportion of trunk biomass. When cutting the sample trees, we found few branches with larger basal diameter for the Chinese fir. This might be the reason why the proportion of branch for the Chinese fir was less than those for the Masson pine and the slash pine. The Chinese fir forest had a relatively large reserve density, so sunlight and space were easily to be the focus of the intraspecific competition. To get more sunlight and space, large proportion of organic matters assimilated by leaves were allocated to stem for height growth. The proportion of foliage biomass for the Masson pine forest was less than those for the slash pine forest and the Chinese fir forest, however, aboveground biomass for Masson pine forest was highest in the four forest types. This indicated that the leaves of the Masson pine might have a higher assimilation rate than that of the slash pine and the Chinese fir.

3.5 Carbon density of dominant species in Qianyanzhou Station

The underground biomass and carbon content of each organ were excluded in our study. In this paper, the underground biomass and carbon density of the four forest types were calculated by previous research results. If the effect of region variability and age were ignored, the biomass and carbon density of the Masson pine forest, the slash pine forest and the Chinese fir forest can be estimated directly based on survey data and the data listed in Table 7. The underground biomass of the Masson pine forest, the slash pine forest and the Chinese fir forest were 10.44, 9.42 and 11.48 t/hm², total biomass were 94.07, 81.61 and 70.42 t/hm², and carbon density were 47.94, 45.14 and 37.52 t/hm², respectively.

4 Discussion and conclusions

The biomass of each branch is highly related to its basal diameter. The coefficient of determination r^2 is larger than 0.9 even if the sample size is more than 150. This indicates that it is suitable to estimate the biomass of each branch with its basal diameter. For equations of leaf biomass, although correlation coefficient is a little lower, they can still pass the significance test. According to correlation coefficient, the best independent variable available to estimate biomass is d^3 , and the best function type is power law equation.

Existing timber volume equations were used to estimate trunk biomass after correction in this paper. Previous studies had proved that when estimating biomass with existing equations without correction, different site conditions would result in error (Wang et al., 1996). Even though the timber volume table released by the local administration was used in the same province, error would still occur (Li et al., 1994). Our study showed that if the existing equations were used without correction, the result would be above or below the correct value. Existing timber volume equations can be corrected with power function before it is used to estimate trunk biomass. The index of the power law equations was used to correct existing equations is nearly 1. This is because the timber volume equations for the

Table 7 Carbon contents of different organs

species	location	age/year	carbon content/%				ratio of aboveground biomass to underground biomass
			stem	branch	leaf	root	
<i>P. massoniana</i> *	Guangxi	23	51.614	47.563	44.617	50.737	8.058
<i>P. elliotii</i> **	Guangxi	16	54.786	55.59	59.33	56.311	7.645
<i>C. lanceolata</i> ***	Hunan	11	47.58	46.81	50.22	47.08	4.808

*Data from Fang et al. (2003b); **Data from Fang et al. (2003a); ***Data from Fang et al. (2002).

same species would be neither the same nor distinctly completely. When correcting timber volume equations, the sample size of our study is a little less. Hence, if more trees sampled, the result would be more reliable.

A lot of studies about the relationship between individual tree biomass and *DBH* had been performed, and many equations were established. The function type of these correlation equations is mostly power law equation. Some other studies proved that power law equation with one parameter *D* can describe the relationship between biomass and *DBH* much better (Whittaker and Marks, 1975; Clough and Scott, 1989). Our study showed that correlation coefficient of the power law equations was larger than those of the exponential and linear equations, and correlation coefficient of equations with independent variable *D* was very high. When D^2H is used as independent variable, however, the correlation coefficient is slightly higher than the equations with independent variable *D*.

Mean *DBH* of dominant species, reserve density, biome biomass and biomass of each organ were distinct for the different forest types in our study. Together with the underground biomass ratio and carbon content measured by others, the carbon density of the Masson pine forest, the slash pine forest and the Chinese fir forest were 47.94, 45.14 and 37.52 t/hm², respectively.

Overall, much time and labor can be saved when the crown biomass is estimated with correlation equations of the branch, and fallen woods can be utilized as well when the correlation equations of the branch are established. Although the cited timber volume equations were corrected prior to use, the small sample size may have a little effect on the reliability of the result. So, more trees sampled would be much better. In addition, the *DBH* range of studied Masson pines (5.8–16.6 cm) in this paper is beyond that of the cited equation for Masson pine timber volume (7.1–25.1 cm). This might also had effect on the result.

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