Branching structure analysis of Scotch pine plantation

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Abstract: Based on the branch analysis data from 30 sample trees of 6 monumental plots for Scotch pine (*Pinus sylvestris* var. *mongolica*) plantation, the branching structure of crown were discussed by analyzing the branching probability, branching pattern, branching angles of primary and secondary branches for different stand conditions and tree sizes in Scotch pine plantation. The mean branching number of primary and secondary branches were 3.84 and 2.80, respectively, and both of the branching probability were followed the normal distribution. The distribution of around the bole for primary and secondary branches is mainly distributed in the range of azimuth (46°-225°) where have a good light condition. A uniform was appropriate to reflect branching pattern around the bole for primary branches, not for secondary branches. The branching angle at upper part of crown was smaller than middle and lower part of crown, and mean branching angle in upper crown and middle or lower crown was 45.6°and 49.4°, respectively. The branching structure of primary branches for different sizes showed the average number of branches in each whorl was similar between dominant and suppressed trees, 3.89 and 3.94, respectively, and they were larger about 0.5 than middle trees. The difference of horizontal distribution for primary branches in each azimuth intervals (45° class size) were 0.24%-2.81% and it was not significant from ANOVA for different tree sizes. The mean branching angles for dominant, middle, and suppressed trees were 48.5°, 42.2°, 50.7°, respectively.
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Key words: Scotch pine, branching probability, branching pattern, branching angle

Introduction

Canopy is the area of photosynthesis, respiration and a series of important physiological activity for trees. The canopy size and structure determine the growth activity and productivity of trees directly (Liu et al., 2008). Branches influence the spatial distribution of leaves, and afford the transportation of the moisture and nutrients among vegetative organs (Ma et al., 2000; Ye et al., 1999). Branching structure determines the complicated degree of the canopy (Hashimoto R. 1990. Cajihara, 1976). So the branching structure plays a vital role for physiological activities such as photosynthesis, nutrient transportation and absorption, and crown shape.

The growth of branches and canopy structure change can be understudied by the quantitative study of branching, and to lay the foundation for establishing a canopy structure prediction model (Deleuze C, 1996. Mäkinen H et al., 1998.). As well as evaluate forest management measures. Based on the branch analysis data of Scotch pine plantation in Jiamusi of northeastern China, the branching structure were studied in closed stands.

Data And Methods

Data

Table 1. Summary of stand variables for plots

No. of plot	Plot area （ha）	Stand age （a）	Crown closure	Mean diameter （cm）	Mean height （m）	Mean height of crown base (m)	Number of trees per hectare（N/ha）
401	0.2	42	0.6	29.0	18.2	6.5	385
402	0.12	42	0.7	23.6	16.9	9.4	650
403	0.06	26	0.8	13.9	8.5	3.7	1 250
404	0.06	33	0.6	13.3	13.9	8.5	1 883
405	0.06	18	0.9	8.6	5.7	2.3	3 633
406	0.08	38	0.8	19.2	15.6	9.6	1 025

6 plots were collected from Scotch pine plantation in jiamusi of northeastern China, located in the region between 130˚28'29" W and 130˚44'34" W in longitude, between 40˚34'40" N and 46˚34'14" N in latitude and 350 m in elevation. In each plot, tree DBH, H, crown length (top to the base of crown), Mean height of crown base, and average crown width were recorded for each tree (Table 1). All trees in the 6 plots were grouped into 5 classes by using the method of mean tree. Then mean diameter and mean height were Calculated for each diameter class. And 5 sample trees

were collected from each plot.

The DBH, H, height of crown base was measured accurately after cutting down the sample tree. The canopy was divided into three layers, respectively, the upper part, middle part and lower part. In each whorl crown structure factors of each branch were measured including azimuth angle, basal diameter, branching angle, branch length and secondary branches number. Table 2 shows the tree variables for branch analysis.

Table 2. Summary of tree variables for branch analysis

Variable	Number of tree	Mean value	S.D.	Minimum value	Maximum value	C.D. （%）
Age（a）	30	33.17	8.80	18.00	42.00	26.53
DBH（cm）	30	18.88	7.10	6.9	33.6	37.61
Height(m)	30	14.08	4.13	7.20	20.00	29.33
Height of crown base(m)	30	7.59	2.74	2.65	11.4	36.10
Crown ratio（%）	30	47.05	9.30	24.50	65.60	19.77
Crown diameter (m)	30	3.58	1.42	1.45	6.65	39.66
Number of primary branches	30	55.77	16.97	33	98	30.43
Number of secondary branches	30	1024.07	536.85	441	2035	52.42

Methods

The branches are divided into primary branches and secondary branches. Growth in the primary branch is secondary branch. The number of primary branches in each whorl and secondary branches in each primary branch was collected. Then on the basis of the results calculated by the formula (1) and (2) the branching probability(R_i)and the average number of branching(N) in each whorl.

$$R_i = X_i \Big/ \sum_{i=0}^{n} X_i \qquad (1)$$

$$N = \sum (i \cdot R_i) \qquad (2)$$

The branch angle was divided into 8 azimuth intervals. Each was 45°. And the number of primary branches and secondary branches was collected in each azimuth interval. Then the uniform distribution is fitted by Statistical 6.0. The X^2 test was done using observed value and the estimates obtained from uniform distribution. The formula (3) is probability density function of uniform distribution.

$$f(x_i) = \frac{1}{n} \qquad (3)$$

Where x_i are azimuth intervals of i, and n is the number of azimuth intervals.

Dominant tree, middle tree and suppressed trees were chose from each monumental plot, and according to their competitive position in the stand respectively called advantage tree, middle tree and suppressed tree. The difference of branching structure was illustrated among different tree size by analyzing of the branching probability, branching pattern and branching Angle.

Results And Discussions

Branching probability

Branching probability reflects the branching ability of tree. Fig. 1 shows that branching probability of primary and secondary branches fit normal distribution. Branching number of primary branches and secondary branches are 3.84 and 2.80 on average. The branching probability of 3, 4 and 5 primary branches are 21.1%、30.9%、24.3% for primary branches respectively, accounting for 76.3% of the total branching probability. Branching probability of less than three and more than five is only 15.2% and 15.2%. The branching probability of 1, 2, 3 and 4 are 13.8%, 22.7%, 28.8% and 19.7% for secondary branches. When the branching number is 1 to 3, branching probability of primary branches is below the secondary branches. When the branching number is 4 to 8, branching probability of primary branches is higher than secondary branches.

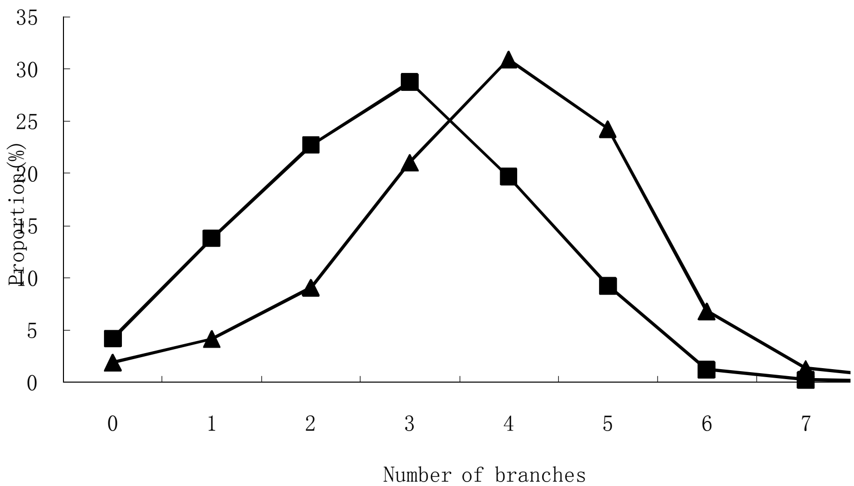

Fig. 1 Probability of primary and secondary branches

The average branching number of primary branches is very close to each whorl for dominant tree and suppressed tree, 3.89 and 3.94 respectively, and more than middle trees about 0.5. When the branching number is more than 4, the probability of primary branches are very similar for dominant tree and suppressed tree, and more than middle tree. The main reason is because the advantage position of dominant, middle and suppressed tree weakens in turn, as well as the ability of nutrient and light competition. Under the condition of nutrient and light enough, its annual growth ability of terminal bud is stronger for dominant tree, so each whorl can produce more branches. And suppressed tree also has its own survival strategies; it can increase the branching number to enhance their competitive ability. Branching number of middle tree more concentrated in 2, 3 and 4, which is closely related with nutrient and light competition in medium.

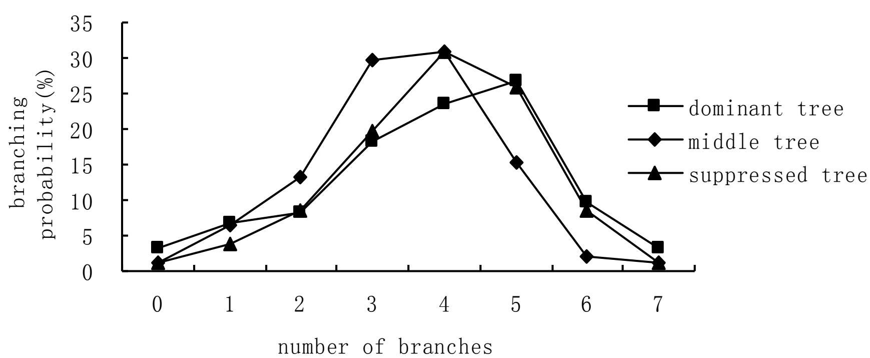

Fig. 2 branching probability of dominant, middle, and suppressed trees

Branching pattern

Branching pattern is a main content in crown structure analysis; it ultimately determines the complicated degree of the crown. Table 3 shows that primary branches distribution percentage is closer to 12% at each azimuth intervals. But it is different about secondary branches among different azimuth intervals.

Table 3 Relative distribution for primary and secondary branches（%）

Azimuth	1～45	46～90	91～135	136～180	181～225	226～270	271～315	316～360
Primary branches	12.21±2.19	12.21±1.73	11.57±2.19	12.97±1.79	13.41±1.83	12.76±2.30	11.69±1.88	11.43±1.77
Secondary branches	11.14±2.08	15.86±3.23	12.30±2.58	13.95±1.61	12.44±1.99	9.85±1.75	11.05±1.96	11.13±3.06

Notes: mean value ± standard deviation

The branches distribution of primary branches for all the 30 sample trees have passed X^2 test（X^2<X^2 0.05(8-2)= 12.592）. It shows horizontal distribution of primary branches fits the uniform distribution for Mongolian pine plantation. This is same to the Doruska and Burkhart's conclusion (Doruska et al., 1994).

Table 4 Chi-square test of uniform distribution for primary branches $X^2_{0.05}(8-2)$= 12.592

No. of tree	X^2 Value	No. of tree	X^2 Value	No. of tree	X^2 Value
Z401—1	5.457	Z403—1	4.523	Z405—1	3.250
Z401—2	8.476	Z403—2	5.109	Z405—2	5.984
Z401—3	5.992	Z403—3	3.979	Z405—3	0.889
Z401—4	2.245	Z403—4	5.047	Z405—4	1.583
Z401—5	1.690	Z403—5	1.499	Z405—5	1.484
Z402—1	4.197	Z404—1	5.931	Z406—1	3.246
Z402—2	5.646	Z404—2	1.774	Z406—2	3.589
Z402—3	5.756	Z404—3	1.238	Z406—3	5.706
Z402—4	5.343	Z404—4	4.914	Z406—4	3.490
Z402—5	1.972	Z404—5	1.968	Z406—5	2.853

The difference of horizontal distribution for primary branches in each azimuth intervals (45° class size) are 0.24%-2.81% (Table 5), and it is not significant from ANOVA for different tree sizes.

Table 5 Azimuth distribution of primary branches for different tree size

Azimuth(°)	Distribution of dominant tree(%)	Distribution of Middle tree(%)	Distribution of Suppressed tree(%)
45.00	11.48	11.35	10.97
90.00	13.39	15.34	13.48
135.00	15.85	16.26	14.42
180.00	12.30	13.80	12.54
225.00	13.11	11.04	12.85
270.00	10.38	12.88	12.85
315.00	12.30	9.51	11.91
360.00	11.20	9.82	10.97
Results	ns	ns	ns

Notes: ns means difference is significant ($P<0.05$)

Branching angle

Branching angle is the most basic element for the formation of trees. It plays a decisive role in the formation of crown shape (Jiang et al., 1999) and also an important indicator to measure the spatial distribution capacity of plants which influences how branches and leaves use light, temperature and CO_2 as well as the spatial distribution of biomass from different components (He, 2005. Cluzeau C N, 1994). In general, branching angles and lighting are directly related (Jiang et al., 1999). Branching angle increases gradually with the increases of branch depth (Deleuze C, 1996. Cluzeau C N, 1994). However, in the plantation of Scotch pines, the average branching angles in the upper, middle and lower crown are respectively 45.6°, 49.4° and 49.4 ° which are not differentiated very much. The average angle of the upper branches is only less than 5 ° smaller than the angles of the middle and lower branches. The branching angles of the middle and the lower crown are the same (Figure 3). The branching angles of the upper crown are mainly in 20° ~ 60° , accounting for 78.3%. The main angles in middle and lower layers are in 30° ~70° with the ratio of 77.1% and 81% respectively. The branching angles which are less than 10° and more than 80° are very less with only no more than 3% in the crown. Branches angles which are greater than 90° are formed mainly due to competition from the adjacent bigger branches, or force of gravity and snow pressure.

Difference of branching angles in the crown is also a manifestation of adaptation to the surrounding environment. Bigger angle indicates much better use of the space resources. Smaller angle helps the absorption of direct light in upper crown where open space, adequate light and less competition. The branches in the middle and lower crown are longer and older with bigger branching angles due to gravity. Coupled with space constraints and mutual competition for light, branching angles in middle and lower crown are increasing and branches tend to flatten which will also help conifers absorb scattered light in the forests (Jin et al., 2003).

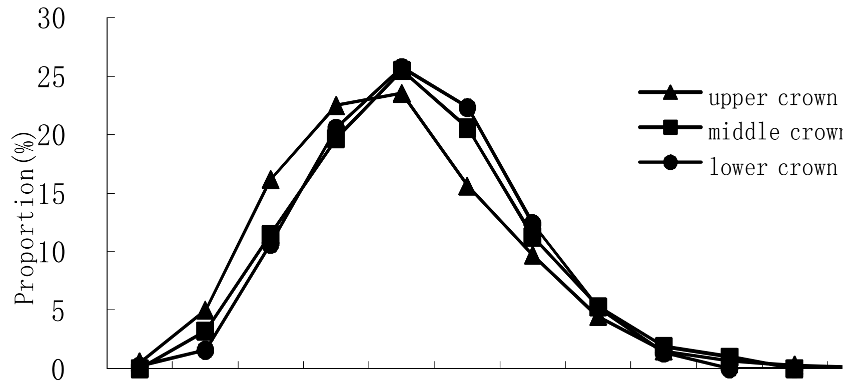

Fig. 3 Probability Proportion of branch angle for primary branches

The average branching angles for dominant, middle, and suppressed trees were 48.5°, 42.2° and 50.7° respectively. When the branching angle is less than 40°, the probability distributions of middle tree is greater than dominant tree and suppressed tree with the figures of 55.17%, 36.34% and 34.92%.There is little difference between dominant tree and suppressed tree. While branching angle is greater than 40°, the probability distributions of dominant tree and suppressed tree are greater middle tree. (See figure 4). The reasons differed. The reasons why branches of dominant tree have bigger branching angles are mainly because they have larger branches and the branch biomass concentrate in the top end and sag by gravity. While for suppressed tree, bigger branching angles are mainly due to their disadvantage competitive location in the stands. Branches tend to flatten in order to make better use of space resources and get access to more scattered light to enhance the adaptation to the environment.

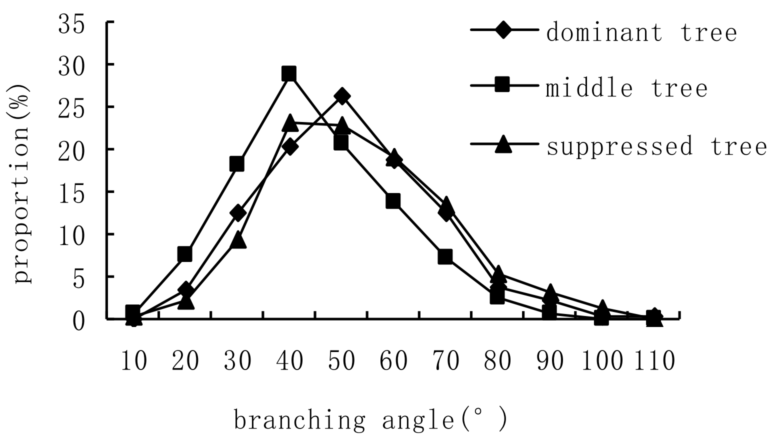

Fig. 4 Distribution of branch angle for different tree size

Conclusions

The mean branching numbers of primary and secondary branches of Scotch pine plantation were 3.84 and 2.80, respectively, and both of their branching probability was followed the normal distribution. 4 was the turning point of branching probability. When branches were less than 4, the primary branching probability was higher than the secondary branching probability. However, when branches were equal to and more than 4, the corresponding primary branching probability was lower than the secondary branching probability.

Horizontal distribution of primary branches of Scotch pine plantation fitted uniform distribution. It was not significant from ANOVA for different tree sizes. Nevertheless, the horizontal distribution of secondary branches was mainly distributed in the range from 46° to 225°, where had good light conditions, and it did not fit uniform distribution.

The probability of branching angle was similarly in different layers of Scotch pine plantation crown, and all of them fitted normal distribution. The branching angle in upper crown tended to left, and was smaller than middle and lower part of crown. The mean branching angle in upper crown was 45.6°, but in middle and lower crown was 49.4°.

The branching structure pattern of different sizes of forest: the branching probability of each whorl of 2-4 branches showed the trend of middle tree>suppressed tree>dominant tree. When there were 4 or more branches, the difference of branching probability was very slight between dominant tree and suppressed tree, but both of their branching probability was higher than middle trees.

The branching angles were different corresponding to different size of trees, and the means for dominant, middle, and suppressed trees were 48.5°、42.2°、50.7°, respectively. When branching angle was less than 40°, the probability distribution of dominant and suppressed tree was less than middle trees. However, when branching angle was greater than 40°, it exhibited the diametrically opposite results.

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