Analysis on the Growth Condition of *Cunninghamia lanceolata* Plantation in Lingnan Forest Farm

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Abstract [**Objectives**] This study was conducted to provide good basic research data for *Cunninghamia lanceolata* plantations in southern Anhui, so as to improve local ecological, economic and social benefits. [**Methods**] A 22-year-old near-mature *C. lanceolata* plantation in Lingnan Forest Farm, Xiuning County, Huangshan City, Anhui Province was investigated and analyzed by sample plot survey. [**Results**] The average DBH value of the *C. lanceolata* plantation at the lower slope was the largest, 24.7% and 19.2% higher than those at the upper and middle slopes, respectively. The average single plant wood volume at the lower slope was 47.6% and 49.1% higher than those in the upper and middle slopes, respectively. However, the average tree heights at various slope positions showed little difference. Meanwhile, all the indexes showed the phenomenon of semi-shady slope > sunny slope > shady slope under different slope directions. Among them, the effect of slope position on DBH was extremely significant, but the effect of slope direction on DBH was not significant, and slope position, slope direction and the interaction of slope direction and slope position had no significant effects on the tree height of the *C. lanceolata* plantation. In addition, slope direction and slope position had extremely significant effects on single plant wood volume. From the overall growth situation of the *C. lanceolata* plantation in Lingnan Forest Farm, the slope position factor had greater effects on various indexes of forest growth than the slope direction factor, mainly manifested in that the lower slope was better than the middle slope, and the middle slope position was better than the upper slope, while although slope direction had some effect on the growth of the *C. lanceolata* plantation, the influence degree was not as significant as that of slope position. [**Conclusions**] This study provides some reference for the adjustment and optimization, development and renewal of *C. lanceolata* plantation structure in the later period in this area, as well as some data support for other theoretical research on economic forests.

Key words Diameter at breast height; Tree height; Single plant wood volume; Slope direction; Slope position

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Carbon neutrality and carbon dioxide peaking were put forward one after another in the world from 2020 to 2021, which has made the status and role of forestry more prominent internationally, and the status and role of forestry in national economic and social development have also increased. Such situation is both an opportunity and a challenge for us. After years of development, China has the largest plantation in the world. However, how to improve forest quality, carbon sequestration capacity and sustainable development capacity is a major challenge that China must face and solve currently[1]. At present, most of China's plantations are in the middle and young age stage, with high carbon sequestration rate and great potential for carbon sink growth, but the problems of single plantation structure, relatively poor biodiversity and susceptibility to diseases can't be ignored[2-3]. Therefore, cultivating healthy, stable, high-quality and efficient plantations is the only way.

First of all, the research is carried out from the selection of germplasms and superior tree varieties. Meng *et al.*[4] mentioned in his study that improved varieties are the basis of intensive management of modern commercial forests, and the selection of improved varieties for afforestation is the guarantee to improve the yield and quality of artificial forests. They compared the one-year growth status of plantation developed with bare-rooted seedlings in the third generation seed orchards of *Cunninghamia lanceolata* in six national level forest improvement bases, and selected the *C. lanceolata* source with the highest growth rate in Sha County of Fujian Province. It provides a reference for improving the planting efficiency of *C. lanceolata* and promoting its application. Chen *et al.*[5] mentioned that "germplasm" is the internal cause of forest culture and management, the basis of forest growth and development, and plays a leading role in forestry production. Breeding of improved forest varieties is the most basic and key link to develop high-yield, high-quality and efficient forestry. Studies have pointed out that the study of growth monitoring and photosynthetic physiological mechanism can provide a theoretical basis for early selection and scientific evaluation of excellent *C. lanceolata* families, and further promote the selection of excellent families and individual breeding. Wu *et al.*[6] conducted a study on the differences in the growth status of geographical *C. lanceolata* sources of different forest ages, in order to screen excellent *C. lanceolata* sources suitable for the development of the experimental area and promote long-term genetic improvement of *C. lanceolata* source levels. The study showed that the age for early selection had a significant impact on shortening the breeding cycle of *C. lanceolata*, and selecting at 10 years old was more conducive to improving the efficiency of genetic improvement in *C. lanceolata*.

Secondly, the growth status of *C. lanceolata* forests mixed with other tree species has been studied. Guo[7-8] studied the

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growth status after interplanting *Phoebe bournei* in *C. lanceolata* forests at the fast-growing stage and the trunk growth stage through experiments. The results showed that whether for *C. lanceolata* forests at the fast-growing stage or the trunk growth stage, interplanting *P. bournei* after thinning was beneficial to the growth of reserved *C. lanceolata*, and it could not only form a multi-layer stand of *C. lanceolata* and *P. bournei*, but also promote the reserved *C. lanceolata* trees. Rebuilding *C. lanceolata* and *P. bournei* multi-layer stands in existing *C. lanceolata* forests has production application value and long-term ecological significance. Fan[9] analyzed the changes of root distribution in mixed *C. lanceolata* and *Liquidambar formosana* forests with pure *C. lanceolata* forests and pure *L. formosana* forests as controls. The results showed that the layering of roots, especially fine roots, of *C. lanceolata* and *L. formosana* in the mixed foreste was obvious, and the water and nutrients in different soil layers were used reasonably and efficiently. The relationship between the roots of the two species was relaxed and coordinated, which made the root distribution expand and the biomass increase, resulting in an additive effect. This additive effect is beneficial to the growth of mixed forests and the improvement of stand productivity. Liu[10], Chen[11] and Xu[12] have also shown that a reasonable proportion of *C. lanceolata* mixed with broad-leaved trees is beneficial to the subsequent growth of *C. lanceolata*.

In addition, the relationship between *C. lanceolata* growth and site conditions has been studied. He[13] conducted a comparative experiment on the effects of mixed afforestation of *C. lanceolata* and *Alniphyllum fortunei* and pure afforestation of *C. lanceolata*. The results showed that site conditions had a great influence on the growth of pure and mixed forests of *C. lanceolata*, and also on the growth of different tree species. Zhu[14] investigated the growth of mixed forests of *C. lanceolata* and *L. formosana* after artificial afforestation for 15 years, and analyzed the effects of different slope directions and different slope positions on the growth of mixed forests of *C. lanceolata* and *L. formosana*. The results showed that under the same site quality grade and management measures, the growth on shady slopes was the largest, followed by semi-shady slopes, and sunny slopes showed the smallest growth in different slope directions.

Chinese scholars have provided strong theoretical support for the renewal and development of *C. lanceolata* plantations through many factors in the process of *C. lanceolata* plantation construction. Investigation and research are mainly carried out through germplasm resources, breeding of excellent varieties, growth status of *C. lanceolata* forests mixed with other tree species, and site conditions for tree growth. However, the former two are the main ones. Due to the traditional intensive management mode of *C. lanceolata* plantations for many years, *C. lanceolata* plantations show various serious ecological problems, such as simple ecosystem structure, soil erosion, declining soil fertility, declining biodiversity and weak ability to resist natural disasters[15-17], so many scholars began to study the construction process of mixed *C. lanceolata* forests. However, we still have a large area of pure *C. lanceolata* forests, and it still takes a long time to adjust and update its structure. Therefore, it is very important to study the theoretical basis of pure *C. lanceolata* forests and provide basic data support for the optimization and development of plantation structure in the later period.

C. lanceolata plantations play an important role in the structure of forest resources in China. If their structure is degraded or unbalanced, it will not only directly affect local ecological benefits, economic benefits and social benefits, but also induce various contradictions and problems. Therefore, this paper attempted to start from the growth status of a *C. lanceolata* plantation in southern Anhui and analyze the relationship between the growth status of the *C. lanceolata* plantation and site conditions in Lingnan Forest Farm from the aspects of slope direction and slope position. It provides good survey data for *C. lanceolata* plantations in southern Anhui in the later period and data support for related research of economic forests.

There are many studies on *C. lanceolata* plantations in academic circles at home and abroad. This paper mainly studied the relationship between the growth status of the *C. lanceolata* plantation and site conditions in Lingnan Forest Farm, deepening the research on the effects of different slope directions and slope positions on the growth status of trees on the basis of previous studies. The research and analysis on the growth status of the *C. lanceolata* plantation in Lingnan Forest Farm can provide some reference for the adjustment and optimization, development and renewal of *C. lanceolata* plantation structure in the later period of this area. In addition, studying the relationship between the growth status of the *C. lanceolata* plantation and slope direction and position in Lingnan Forest Farm can provide some data support for other theoretical research on economic forests, and thus accelerate the transformation of theoretical research results to productivity and make theory more effective in guiding practice.

General Situation of Research Area and Research Method

General situation of research area

The survey was carried out in the local area of Huangtuling, Lingnan Forest Farm, Xiuning County, Huangshan City, Anhui Province, where the landform belongs to the typical hilly and mountainous area in southern Anhui, with the east longitude of 118°9′ and the north latitude of 298°27′. The sample plots were temporary, and the vegetation type was multi-layer structure of arbor, shrub and grass. The soil type was yellow loam. The altitude was about 250 m, and the slope of the sample plots was between 30° and 35°.

Research method

The research method adopted in this experiment was the sample-plot survey method. Firstly, the slope direction of plots was distinguished and divided into three slope directions: shady slope, sunny slope and semi-shady slope. Then, according to the slope length, the slope surface was divided into three positions: upper, middle and lower. The vertical projection areas of sample plots were all 100 m^2, and three replicates were set for each slope direction. The *C. lanceolata* plantation selected in this experiment was a near-mature forest of 22 years old, and the slope of the sample plots was between 30° and 40°. Each tree in the sample plots were measured for DBH and tree height. The average tree height, average DBH and average single plant wood volume in the upper, middle and lower slopes were calculated and the results were analyzed. Two-factor analysis of variance was performed in Excel to compare the effects of different slope directions and different slope positions on average tree height, average DBH and average single plant wood volume.

Volume calculation formula:

$$V = \frac{1}{2} \times g_{1.3}(H + 1.3) \quad (1)$$

In the formula, V is the average single plant wood volume; $g_{1.3}$ is the cross-sectional area of breast height; and H is the tree height.

Results and Analysis

Values of average DBH, average tree height and average single plant wood volume corresponding to different slope directions and positions were obtained by sorting out and calculating the data obtained by measuring *C. lanceolata* trees in 27 sample plots. The results are shown in Table 1. Generally speaking, there were great differences in average DBH and average single plant wood volume at different slope positions. The average DBH at the lower slope was the largest, and 24.7% and 19.2% higher than that at the upper and middle slopes positions, respectively. The average single plant wood volume at the lower slope was also 47.6% and 49.1% higher than those in the upper and middle slopes, respectively. However, various slope positions caused no great difference in average tree height. Under different slope directions, all the indexes show the phenomenon of semi-shady slope > sunny slope > shady slope.

Table 1 Comparison on growth status of *C. lanceolata* under different slope directions and positions

Slope direction	Average DBH//cm			Average tree height//m			Average ingle plant wood volume//m^3		
	Upper slope	Middle slope	Lower slope	Upper slope	Middle slope	Lower slope	Upper slope	Middle slope	Lower slope
Sunny slope	11.16	12.67	16.05	10.92	12.05	11.94	0.059 4	0.082 2	0.125 4
Shady slope	11.00	12.31	14.14	9.93	10.50	10.13	0.053 5	0.070 7	0.089 9
Semi-shady slope	14.28	13.15	15.22	13.45	9.94	12.74	0.119 5	0.077 1	0.128 0

In order to test the effects of slope direction, slope position and the interaction between slope direction and slope position on the growth of the *C. lanceolata* plantation, it is necessary to make following assumptions about the above three factors:

(1) Assumption about slope direction factor:

H_{01}: The slope direction factor had no significant effect on the dependent variable

H_{11}: The slope direction factor had a significant effect on the dependent variable

(2) Assumption about slope position factor:

H_{02}: The slope position factor had no significant effect on the dependent variable

H_{12}: The slope position factor had a significant effect on the dependent variable

(3) Assumption about the interaction factor of slope direction and slope position

H_{03}: The interaction factor of slope direction and slope position had no significant effect on the dependent variable

H_{13}: The interaction factor of slope direction and slope position had a significant effect on the dependent variable

Table 2 Analysis of variance on the effects of slope direction and slope position on DBH

Source of variance	*SS*	*df*	*MS*	*F*	*P*-value	Fcrit
Slope position	45.437 4	2	22.718 7	11.689 0	0.000 6	3.554 6
Slope direction	13.522 3	2	6.761 2	3.478 7	0.052 8	3.554 6
Interaction	13.527 3	4	3.381 8	1.740 0	0.185 1	2.927 7
Internal	34.984 7	18	1.943 6			
Total	107.471 7	26				

$F > Fcrit$ means rejecting the original hypothesis, and $F < Fcrit$ stands for accepting the original hypothesis; and P-value < 0.05 indicates that the source of variance has a significant effect on the dependent variable, and P-value < 0.01 indicates that the source of variance has an extremely significant effect on the dependent variable. The same below.

From the comparison in Table 2, it was concluded that $F_{slope\ position} > Fcrit$, so the original assumption H_{02}: the slope position factor had no significant effect on the dependent variable, was rejected. That is to say, the line factor of the test, that is, the slope position factor, had a significant effect on the dependent variable, *i.e.*, DBH. Moreover, $P_{slope\ position}$-value < 0.01 indicated that slope position had an extremely significant effect on DBH.

$F_{slope\ direction} < Fcrit$, so the original hypothesis, *i.e.*, H_{01}: the slope direction factor had no significant effect on the dependent variable, was accepted. Similarly, the original hypothesis H_{03}:

the interaction factor of slope direction and slope position had no significant effect on the dependent variable, was accepted.

It could be seen from Fig. 1 that the DBH of the *C. lanceolata* plantation increased gradually with the decrease of slope position, whether for the sunny slope, shady slope or semi-shady slope. However, the DBH of *C. lanceolata* on the semi-shady slope was not much different at different slope positions, and the DBH on the upper slope was larger than those on sunny and shady slopes. The DBH of *C. lanceolata* on the shady slope was obviously different at different slope positions, while the DBH of *C. lanceolata* on the sunny slope was most obvious at different slope positions.

From Table 3, it could be concluded that $F_{slope\ position}$, $F_{slope\ direction}$ and $F_{interaction}$ were all smaller than their respective corresponding Fcrit, so the original assumptions, H_{01}: the slope direction factor had no significant effect on the dependent variable, H_{02}: the slope position factor had no significant effect on the dependent variable, and H_{13}: the interaction factor of slope direction and slope position had no significant influence on the dependent variable, were all valid. That is to say, the interaction factor of slope direction and slope position had no obvious effect on tree height of the *C. lanceolata* plantation.

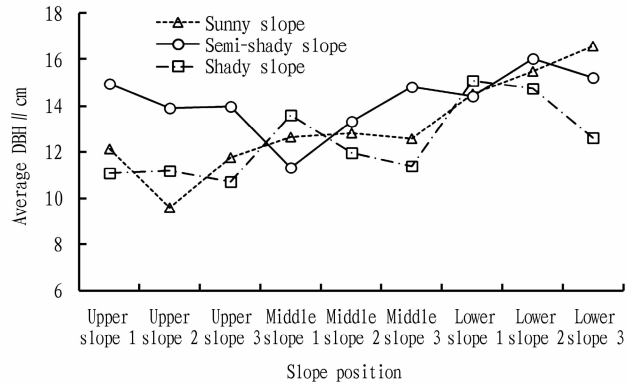

Fig. 1 Distribution of average DBH of *C. lanceolata* under different conditions

Table 3 Analysis of variance on the effects of slope direction and slope position on tree height

Source of variance	*SS*	*df*	*MS*	*F*	*P*-value	Fcrit
Slope position	2.994 7	2	1.497 3	0.579 7	0.570 2	3.554 6
Slope direction	17.123 2	2	8.561 6	3.314 4	0.059 5	3.554 6
Interaction	20.421 9	4	5.105 5	1.976 5	0.141 4	2.927 7
Internal	46.496 1	18	2.583 1			
Total	87.035 9	26				

As shown in Fig. 2, the change trends of *C. lanceolata* height at different slope positions were all not obvious whether for the sunny slope, shady slope or semi-shady slope. However, there were some differences in the height of *C. lanceolata* trees in different slope directions, and the height of trees on the shady slope was slightly lower than those on the sunny slope and semi-shady slope. Moreover, at the upper position of the semi-shady slope, the height of trees showed great differences between different plots.

From the data in Table 4, the following conclusions could be drawn: $F_{slope\ position} > Fcrit$ and $P_{slope\ position}$-value < 0.01 indicated that slope position factor had an extremely significant effect on the single plant wood volume of the *C. lanceolata* plantation. Similarly, the factor of slope direction also had an extremely significant effect on it. The interaction factor of the two also had a significant effect on it.

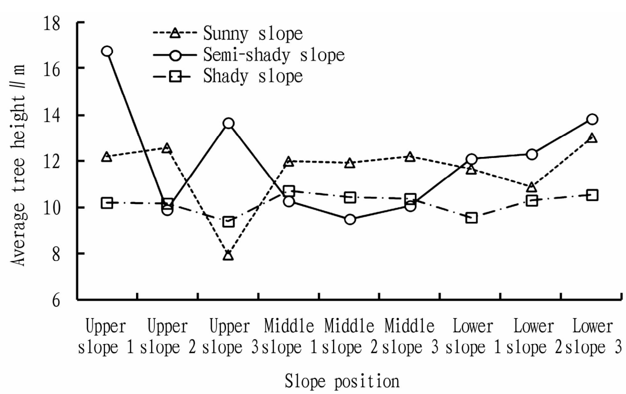

Fig. 2 Distribution of average tree height of *C. lanceolata* under different conditions

Table 4 Analysis of variance on the effects of slope direction and slope position on single plant wood volume

Source of variance	*SS*	*df*	*MS*	*F*	*P*-value	Fcrit
Slope position	0.008 4	2	0.004 2	11.170 2	0.000 7	3.554 6
Slope direction	0.006 1	2	0.003 1	8.154 5	0.003 0	3.554 6
Interaction	0.004 8	4	0.001 2	3.212 4	0.037 2	2.927 7
Internal	0.006 7	18	0.000 4			
Total	0.026 0	26				

It could be seen from Fig. 3 that single plant wood volumes of the sunny slope and shady slope generally presented the phenomenon of lower slope > middle slope > upper slope, and the single plant wood volume of the shady slope at the middle and lower slopes was obviously smaller than that of the sunny slope. As to the sunny and semi-shady slopes, there was no obvious difference in single plant wood volume between the middle and lower slopes. However, the single plant wood volume of the semi-shady slope was much higher than that of the sunny slope at the upper slope position, and the single plant wood volume of the semi-shady slope was also quite different between different sites.

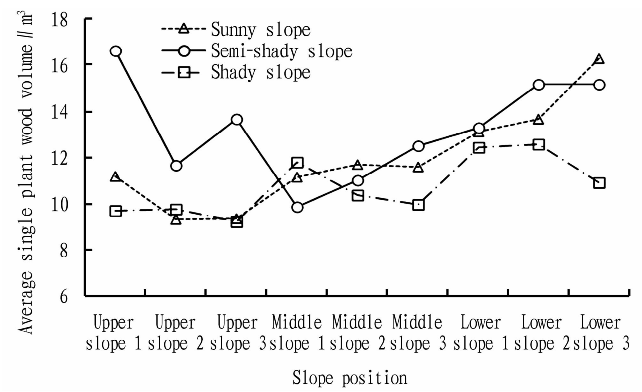

Fig. 3 Distribution of average single plant wood volume of *C. lanceolata* under different conditions

Conclusions and Discussion

The results of this study showed that different slope positions had obvious effects on DBH growth of the *C. lanceolata* plantation. Generally speaking, the average DBH at the lower slope was the largest, followed by the middle slope taking the second place, and the upper slope with the smallest value. This conclusion is consistent with the results of previous studies[10], which may be due to the continuous transfer of soil and litter from top to bottom under the action of external force, which leads to a thicker soil layer as the slopes go down, and more organic matter and mineral elements are accumulated, and the DBH of *C. lanceolata* grows better as the slopes go down. However, the increase of DBH of *C. lanceolata* on the semi-shady slope from the upper slope to the lower slope was not obvious, which might be because the selected three semi-shady slopes were not too long, and the slope gradients were not too large, and the understory shrub and grass vegetation cover was relatively dense, making the soil layer distribution at the upper, middle, and lower slope positions more uniform, which was conducive to maintaining and improving soil quality[18] and resulted in less significant differences in the growth of *C. lanceolata* trees.

After analyzing the effects of various factors on the average tree height of *C. lanceolata*, the conclusion was that although the average tree height was different under different conditions, the effects of slope position, slope direction and the interaction between slope position and slope direction on the tree height of the *C. lanceolata* plantation were not significant, which is consistent with the conclusion of Dr. Chen Weijun's preliminary study on the cultivation system of *C. lanceolata* in different producing areas in China[19]. However, the tree height of the semi-shady slope changed obviously at different slope positions, and there were also great differences between different plots at the same slope position level, which might be because the site conditions were different between different plots, such as soil thickness, soil density, and vegetation coverage under forests. The study of Lin *et al.*, effects of undergrowth plant on soil fertility in *C. lanceolata* plantation[20], showed that the contents of organic matter, total N, total P, hydrolyzable N and available P in the soil layer basically increased with the coverage of understory plants, which also explained the reason why the average DBH value of the semi-shady slope at the middle and upper slope positions was obviously larger than those in the sunny and shady slopes in various sample plots.

In the analysis of the effects of micro-site *C. lanceolata* plantation stock, it is concluded that slope position and slope direction have a very significant impact on it, which is consistent with the investigation results of some scholars in the early stage. As for average single plant wood volume, the value of the semi-shady slope at the upper slope position changed greatly between different plots, which might be because the stand density was not the same between various sample plots. Cao Xinying and Cao Zhihua both indicated in their papers that proper tending and thinning was beneficial to the growth of DBH of single tree and the increase of single plant wood volume[21-22]. The highest stand density among the three sample plots located on the upper slope of the semi-shady slope was 31 trees per 100 m^2, and the lowest value was only 23 trees per 100 m^2. The *C. lanceolata* plantation surveyed in this survey were all over 21 years old, and they were affected by various factors such as wind breaking, snow pressing and pest infestation for over 20 years, which might be one of the reasons for the significant differences in stand density between different sample plots[3].

Although this survey showed the effects of slope direction and slope position on the growth of *C. lanceolata* plantations to some extent, there is still a lack of research perspectives. For example, the significant difference in tree height under the same slope position condition, as well as the impact of soil physicochemical properties on the growth of *C. lanceolata*, requires long-term observation.

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