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# Study on Final Felling Age of Chinese Fir Plantation With Different Site Index in Guangxi

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## Abstract

Based on 156 analytic trees' samples from 128 plots of Chinese fir plantation in Guangxi and 269,810 Chinese fir plantation subcompartments' data from Guangxi forest management inventory, we researched the growth process of the average tree of Chinese fir plantation with different site index and the rule of density changes of Chinese fir plantation. By optimizing model structure, we established the model of volume growth and the model of technical volume ratio of Chinese fir plantation with different site index and calculated the technical volume and the present value of pure income of each age`s Chinese fir plantation, regarding the maximum present value of annual average net benefits as the judging index of economic maturity age and the economic maturity age as the final felling age. Results show that the final felling ages of Chinese fir plantation with different site index have small difference. The final felling age of Chinese fir plantation with different site index—12, 14, 16, 18, 20 is: 23 years, 23 years, 22 years, 22 years, 23 years, respectively.

**Key words:** Chinese fir plantation; Final felling age; Growth model; Site index

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## INTRODUCTION

Chinese fir ( Cunninghamia lanceolata) is a native tree species in Guangxi, which local people plant traditionally. It is also one of the main planting tree species of fast-growing fertility plantations in southern China (Zhou et al., 2001; Chen, 2010). At the end of 2009, the coverage of Chinese fir is 1.2892 million $hm^2$ in Guangxi. At present, State Forestry Administration regulates the final felling age of Chinese fir timber forest is 26 years nationwide. According to the desire of the forest operators cultivating short-term small diameter timber, Guangxi Forestry Department identifies the final felling age of Chinese fir timber forest as 16 years. And some operators even propose the final felling age of Chinese fir forest is 10-12 years. Which final felling age should we choose to get the maximum economic benefit? This is the problem both the forest operators and managers extremely concerned. According to forest management theory, methods to determine the final felling age of the timber forest mainly include quantitative maturity, technical maturity and economic maturity (Zhou et al., 2001; Chen, 2010; Zhang, 1988; Wang & Liu, 1992; Lu, 1993; Wu et al., 2010; Li et al., 2013). These three methods determine the final felling age using distinct indicators respectively. Quantitative maturity method is that the stand should be cut when the stand total growth rate or the annual average growth of volume reaches the largest (Zhang, 1988; Wang & Liu, 1992 Lu, 1993; Wu et al., 2010; Li et al., 2013). Based on technical maturity method, cutting should be considered after the target timber forest has formed and when its annual average yield reaches the maximum (Li et al., 2013; Xu et al., 1994; Xu et al., 1997; Ding, 1998; Wang et al., 2000). Economic maturity method is the stand should be felled when its economic benefit reaches the maximum (Zhou et al., 2001; Chen, 2010; Huang et al., 2004; Liu et al., 2011). The purpose of timber business is to obtain the highest production, namely the biggest economic benefits. So to determine the final felling age of the timber forest according to economic maturity method can achieve the goal of management of timber forest. Because of the influence of forest plant density, there is a distinctly disparity between the single tree and the stand overall in growth and maturity (Zhang, 1988; Wang & Liu, 1992; Wu et al., 2010). To study the growth process of the overall forest stand can directly reveal the growth regularity. But it needs long-term regular measurement by setting the fixed standard plots, a lot of manpower and financial resources. This kind of research method is of poor efficiency. Through one-time survey such as forest management inventory, we can get the volume data of age sequence of forest stand to build volume growth process model. Because of disparities among survey subcompartments in the site conditions and the stand plant density, the homogeneity of the sample data is extremely poor. So the precision of the growth model which is based on these sample data does not meet the demand. In order to ensure the precision of growth model and improve the efficiency, we try to research the final felling age from three aspects including the technical volume accumulation of individual tree, the stand technical volume accumulation and the stand economic benefits, namely: (a) Select the average trees of the mature or overmature forest stand to be fell, analyze their stems and research the volume growth process of individual tree and the accumulation process of technical volume. (b) Study the change law of tree density of practical stands, analyze the correlation between the forest stand growth and the single tree growth and research the technical volume accumulation process of forest stand. (c) Calculate the present value of economic pure income of different age stand according to forest management cost and average price of timber and social discount rate. We determine the economic maturity age of the forest stand on the basis of the maximum annual average economic net income of forest management, regarding the economic maturity age as the final felling age.

## 1. MATERIALS AND METHODS

### 1.1 The Study Area Profile

We selected the area where Chinese fir is distributed in Guangxi Zhuang Autonomous Region— east-west across about 760 km (104.47-112.07 degrees east longitude), north-south across about 670 km (20.9-26.4 degrees north latitude). According to the geographical location and the growth conditions of Chinese fir forest, the region of Chinese fir could be divided into the center region and the general production area. The northern Guangxi were the center region. The southern Guangxi were the general production area. In northern Guangxi, the annual average temperature was 18-21℃. The average temperature was 6-2℃ in January. The average temperature was around 28℃ in July. In southern Guangxi, the annual average temperature was 21-23℃. The average temperature was 12-15℃ in January. The average temperature was 28-29℃ in July. The Chinese fir in Guangxi was generally planted in the mountains and hills. The woodland soil included red soil, mountain red soil and deep red soil. The soil fertility in medium or above was good for the growth of Chinese fir.

### 1.2 Material Collection And Processing

#### 1.2.1 Analytic Trees Data Collection and Treatment

We chose mature or overmature forest of Chinese fir with crown density between 0.4-0.8 from the center region and the general production area respectively and selected sample plots according to the disparities of site index to ensure the number of samples in each site index forest stand was equally distributed. Sample plots were designed to be square or rectangle and the area of each sample plot was 900 $m^2$. The diameter at breast height of each tree within the sample plots was measured, then the average diameter at breast height of trees in the sample plots were figured out. We cut one or two normal average trees from each sample plot and analyzed their stems.

We cut down the selected average trees, measured their height and analyzed their stems. Each stem could be divided into 10 sections with equal length and intercepted discs at each paragraph points, at the breast height (1.3 m) and at the middle of the first paragraph. From east-west and north-south direction, we measured diameter over bark of each disc and the diameter of each growth ring. According to the total length of each tree we analyzed, the height of the discs, the diameter of each annual ring of each disc, we calculated the trunk volume of each age of the trees we analyzed, namely the trunk volume inside bark of each age. We drew figure to study the relation between the diameter of each growth ring of each disc and the height of each disc. We finally got the normal sample data of 156 sample trees eliminating abnormal sample data. Data of each sample tree included the volume inside bark and the technical volume of each age. The number of samples according to different site index— 12, 14, 16, 18, 20, were 136, 152, 322, 152, 322 groups, respectively.

#### 1.2.2 The Subcompartment Data of Forest Management Inventory Collection and Processing

Using data of forest management inventory in 2009, we selected the data from Chinese fir forest subcompartment with forest stand average diameter at breast height not less than 5 cm and forest canopy density greater than 0.3. We established data set of each age sequence of Chinese fir forest - the number of trees per hectare and calculated the standard deviation of the tree`s number per hectare respectively. We got 26,9810 modeling samples of each age sequence excluding extreme samples by 3 standard deviations.

#### 1.2.3 Major Economic Indicators of Chinese Fir Forest Management

According to the investigation results of construction investment of Chinese fir forest afforestation project in Chinese fir forest planting area in Guangxi during 2013-

2015, construction investment from the first year to the third year could be divided into 6 items. The average construction investment per hectare included forest land clearing costing 1,100 yuan, soil preparation and digging costing 1,970 yuan, purchase of nursery stock costing 1,155 yuan, seedling planting and replanting costing 525 yuan, purchase of fertilizer costing 3,740 yuan, fertilization and artificial tending costing 2,600 yuan, totaling 11,090 yuan. After the fourth year the expenditure of annual average forest management was about 75 yuan/$hm^2$ and the woodland rent was RMB 600 /ha. year.

The survey and design fee of felling area was RMB10 per cubic meter of wood. The cutting and yarding of timber cost RMB 50/$m^3$. The expenditure of transportation was RMB 40 /$m^3$. The cultivation fund was RMB 40/$m^3$.

According to the timber market survey results of Chinese fir forest in Guangxi during 2013 - 2015, Chinese fir timber average price was 1,100 yuan/$m^3$.

### 1.3 Methods of Determining the Final Felling Age

Considering the objective of timber forest management, the best final felling age of Chinese fir timber forest is the age when the operator got the maximum economic benefit, which could be demonstrated by the economic maturity age of Chinese fir plantation. Stand economic maturity is the growth stage of the stand that implementing final felling can obtain the maximum economic benefits. Stand economic maturity ages included five types, namely stand mature age of the highest total benefit, stand mature age of the highest net benefit, stand mature age of the highest land net benefits, stand mature age of the maximum benefit rate, stand mature age of the biggest social public benefits including indirect pecuniary benefits (Zhou et al., 2001; Chen, 2010; Huang et al., 2004; Liu et al., 2011; Dong et al., 2014). These five kinds of economic mature age came from different standpoints. Timber forest management is an investment. What timber forest operators care were the economic benefits and the time value of money. So our study calculated the present value of the annual average net benefits. We regarded the age obtaining the highest present value of annual average net benefits as the best final felling age. The method was as follows: (a) By using data of analytic trees, we researched the rule of average volume growth of Chinese fir forest, established growth model and calculated the volume and the yield of technical volume of each age; (b) according to the subcompartment data of Chinese fir plantation, we studied the change rule of tree density of Chinese fir plantation, built stand age—tree number function model and calculated theoretical tree number per hectare of different age; (c) on the basis of the technical volume of average tree of the stand and the tree number per hectare, we figured out the technical volume of the stand of different age; (d) we calculated the average technical volume growth of the stand of different age; (e) according to the recent wood market price and the cost of logging, We calculated the sales profit; (6) deducting the cost of afforestation and management from the present value of sales profit, we got the present value of the pure income of stand management; (7) we calculated the annual average net benefits of Chinese fir plantation management and determined the best final felling age according to the stand age when the annual average net benefits was the maximum.

## 2. RESULTS AND ANALYSIS

### 2.1 The Maturity Age of Average Tree of Stand

#### 2.1.1 Average Tree Quantitative Maturity Age of Stand

Utilizing the sample data of analytic trees, we chose the growth models such as Logistic model, Richards model, Gompertz model, Conic model, Weibull model, Korf equation, Polynomial equation (Chen, 2010; Li et al., 2011) to fit and optimize the model. We found that Richards model was the optimal model. Richards model structure is as follows:

$$V = c_1 \times (1 - \exp(-c_3 \times A))^{c_2} . \quad (1)$$

Among this model structure, $V$—average tree volume inside bark, $A$—average tree age, $c1$, $c2$ and $c3$-undetermined parameters.

**Table 1**
**Parameters of Volume Inside Bark Growth Model and the Correlation Coefficient**

| Modeling unit | Parameter *c*1 | Parameter *c*2 | Parameter *c*3 | Correlation coefficient *R* |
|---|---|---|---|---|
| Site index 12 | 0.12112 | 15.09581 | 0.16055 | 0.98622 |
| Site index 14 | 0.22132 | 4.814 | 0.0859 | 0.98321 |
| Site index 16 | 0.30942 | 3.77165 | 0.07031 | 0.91626 |
| Site index 18 | 0.41888 | 3.35801 | 0.05998 | 0.90625 |
| Site index 20 | 0.53588 | 3.38438 | 0.05907 | 0.8909 |

According to the model, we figured out the average tree volume inside bark of each site index stand of each age and the annual average increment of volume inside bark of each age. The maturity age of volume inside bark

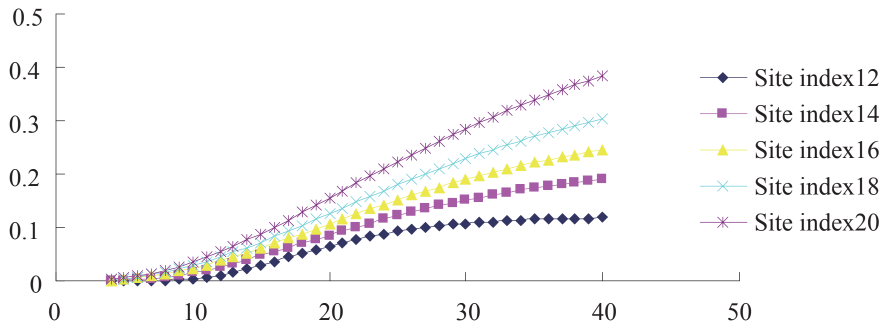



**Figure 1**
**Growth Process of Volume Inside Bark of Average Tree**

of average tree was the year when the annual average of volume inside bark of standing average tree reached the maximum. By calculating, we concluded the maturity age of volume inside bark of average tree with different site index—12, 14, 16, 18, 20 was 26, 30, 32, 35, 35 years, respectively.

#### 2.1.2 Stand Average Tree Technical Maturity

##### 2.1.2.1 Minimum Age Available For Technology of Stand Average Tree

Standards of technical maturity varied with different purposes of cultivating wood. Such as fiber materials for papermaking, when the wood tracheid length, tracheid length-width ratio, basic density and chemical composition content met the basic requirements for papermaking, the wood reached its technical maturity (available for technology). If the wood was used for pitwood, pillow wood and furniture, etc., the wood was available for technology when its length and diameter inside bark at small end must meet the corresponding indicators. Some precious timber species reached technology available when the heartwood formed and the heartwood length and diameter at the small end met certain requirements. Chinese fir wood used for furniture, tool and building materials required the diameter at small end reaching 4 cm and its length varied with different purposes. Our study selected the basic size of main type of wood, namely 4 m, 6 m length, 4 cm, 6 cm diameter at small end as the index of technology available.

According to the data of analytic trees, we determined the age when the diameter of stand average tree trunk at 4 m, 6 m height reached 4 cm, 6 cm, namely the minimum age available for different technical purposes. The data was shown in Table 2.

In Table 2, Site index-stand site index, Age1—the age when the diameter of stand average tree trunk at 4 m height reached 4 cm, Age2—the age when the diameter of stand average tree trunk at 4 m height reached 6 cm, Age3—the age when the diameter of stand average tree trunk at 6 m height reached 4 cm, Age4—the age when the diameter of stand average tree trunk at 6 m height reached 6 cm.

**Table 2**
**Minimum Age of Stand Average Tree Available for Technology**

| Site index | Age1 | Age2 | Age3 | Age4 |
|---|---|---|---|---|
| 12 | 12.1 | 13.8 | 14.5 | 16.7 |
| 14 | 10.2 | 12 | 11.8 | 13.9 |
| 16 | 9 | 10.8 | 10.9 | 12.9 |
| 18 | 7.5 | 8.9 | 9.5 | 11 |
| 20 | 7.5 | 8.9 | 9 | 10.6 |

*Note.* Unti: Years.

##### 2.1.2.2 Stand Average Tree Technical Maturity Age

Using the sample data of analytic trees, we calculated the ratio between stand average tree technical volume (volume inside bark with diameter inside bark at small end reached 4 cm and length was greater than 4 m and its volume inside bark. We established mathematical model of the technical volume ratio varied with age. We chose growth models such as Logistic model, Richards model, Gompertz model, Quadratic curve model, Weibull model, Korf equation to fit and optimize the model. We found that the Logistic model was optimal. The structure of Logistic model is as follows:

$$Pv = c_1/(1 + c_2 \times \exp(-c_3 \times A)) \qquad (2)$$

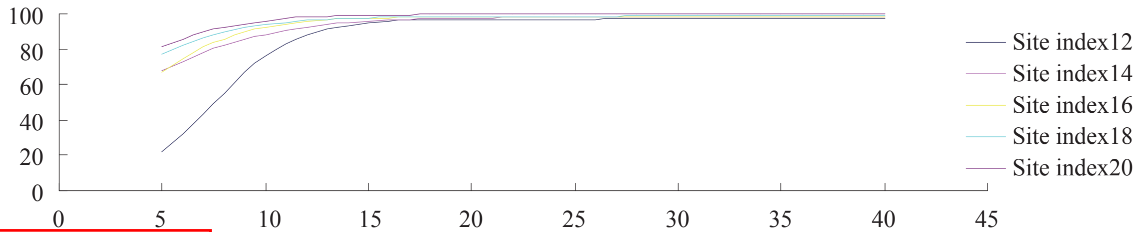
Among the model structure above, $Pv$ – ratio between the technical volume and volume inside bark, $A$ – tree age, $c1$, $c2$, $c3$ –undetermined parameters.

According to different site index stand, we built the mathematical model of ratio between the average tree technical volume and volume inside bark. The model fitting results were shown in Table 3 and Figure 2.

Using the above model (1), model (2) and its parameters, we calculated the quantity of technical volume of each age of stand average tree with different site index and annual average quantity of technical volume of each year. The technical volume maturity age was the age when the annual average quantity of technical volume was the maximum. By calculating, we concluded that the average tree technical maturity age of different stand site index—12, 14, 16, 18, 20, was 26, 30, 32, 35, 35 years respectively, which were greater than the minimum age available for technology of different timber species listed in Table 2. The stand average tree technical maturity age and its quantitative maturity age ( maturity age of volume inside bark ) were exactly the same.

**Table 3**
**Parameters of Ratio Model of Average Tree Technical Volume and the Correlation Coefficient**

| Modeling unit | Parameter *c*1 | Parameter *c*2 | Parameter *c*3 | Correlation coefficient *R* |
|---|---|---|---|---|
| Site index 12 | 97.04255 | 40.64271 | 0.49839 | 0.90824 |
| Site index 14 | 98.34699 | 1.82783 | 0.27674 | 0.87377 |
| Site index 16 | 98.51048 | 3.18605 | 0.38450 | 0.89510 |
| Site index 18 | 98.73865 | 1.57927 | 0.34111 | 0.85593 |
| Site index 20 | 99.91344 | 1.29759 | 0.34600 | 0.89459 |

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Model

Chinese fir in Guangxi was nts/hectare. There was the habit for fostering in the relatively large planting area, which implemented one or two times commonly. The first intermediate cutting was implemented in 7-10 years and the second time in 12-15 years. The planting area cultivating small- middle diameter wood of Chinese fir carried out only one intermediate cutting, which covered about 50% of timber forest area of Chinese fir in Guangxi. About 15% of planting area of Chinese fir in Guangxi cultivating middle-large diameter wood implemented the second thinning. The rest of the planting area about 35% of Chinese fir in Guangxi, due to the shortage of technique and manpower, was of extensive management without thinning. With the canopy closure became excessive, this part of Chinese fir forest without thinning in young-middle age competed for space and nutrition. So part of plants died by extrusion, the plant density reduced with the forest aging gradually. When the stand became nearly ripe, because of the natural thinning or unlawful felling, plant density also gradually reduced. The results of forest management inventory fully revealed the phenomenon that Chinese fir forest plant density gradually reduced along with the forest aging. There was data from 269,810 survey subcompartments of Chinese fir forest with diameter at breast height were greater than 5 cm in Guangxi. The relation between the number of trees with diameter at breast height was greater than 5 cm and forest age was illustrated in the Figure 3 below.

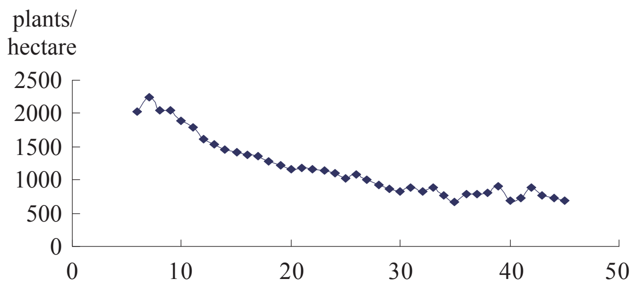


**Figure 3**
**Relational Graph of the Number of Trees and Age**

We found that Richard growth curve model could well express the relationship between the number of trees per hectare and its age, the model structure was as follows:

$$N = c_1 \times (1 - \exp(-c_3 \times A))^{c_2}. \qquad (3)$$

Among the model structure above, *N*—the number of trees, *A*—tree age, *c*1, *c*2, *c*3 –undetermined parameters.

The parameters of the model fitting results were shown in Table 4 below.

**Table 4**
**The Number of Trees and Age and the Correlation Coefficient**

| Parameter *c*1 | Parameter *c*2 | Parameter *c*3 | Correlation coefficient *R* |
|---|---|---|---|
| 102.19937 | -0.62200 | 0.00100 | -0.97753 |

**2.2.2 Stand Quantitative Maturity Age and Technical Maturity Age**

Within a certain range of stand plant density, forest timber production and stand plant density were closely positively correlated (Zhang, 1988; Wang & Liu, 1992). The yield of stand timber per hectare was the product of the volume of stand average tree and the number of trees per hectare. Utilizing the average tree volume inside bark growth function model (1) and the stand plant density model (3), we calculated the volume inside bark of each age of stands with different site index. Combined with the technical volume ratio model (2), We figured out technical volume of each age of stand with different site index. We calculated the annual average volume inside bark and technical volume. We identified the age when the annual average volume inside bark and the annual average technical volume reached the maximum as the stand quantitative maturity age and the technical maturity age, respectively.

#### 2.2.3 Stand Economic Maturity Age

The stand age when the present value of the stand annual average net benefits was the highest was identified as the forest economic maturity age, the steps of calculation were as follows:

(a) To calculate the sales income of technical volume of stand per hectare, the formula was as follows:

$$B = V \times (P - S - C - F) .$$

Among the above formula: *B*—sales revenue of technical volume per hectare, *V*—the quantity of technical volume per hectare, *P*—sales price of technical volume per cubic meter, *S*—the cost of technical volume for investigation and design of cutting area per cubic meter, *C*—the cost of technical volume for cutting and transportation per cubic meter, *F*—the forest cultivation fund of technical volume per cubic meter.

(b) To calculate the present value of sales revenue and the cost for management and protection of the stand per hectare. The formula was as follows:

$$P = \frac{F}{(1 + R)^A}$$

Among the above formula: *P*—the present value of the sales revenue or the cost for stand management and protection ,F - sales revenue or cost for stand management and protection (future value), *A*—stand age, *R*—average social discount rate. Reference to *The Construction Project Economic Evaluation Method and Parameter (Third Edition)*, the average social discount rate is 8% (The National Development and Reform Commission, para.3, 2006).

(c) To calculate the net benefits of forest management: the present value of the sales pure income of technical volume per hectare minus the present value of the cost of construction investment, land rent, and forest management and protection per hectare was the net benefits of forest management per hectare.

(d) To determine economic maturity age of the stand: According to the pure benefits of each age of stand management per hectare, the age when the annual average net benefits of the stand reached the maximum was identified as the economic maturity age of Chinese fir plantation.

The pure benefits of Chinese fir forest with site index 16 were calculated. The results were shown in Table 5 below. when the stand age was 32 years, the annual average quantity of technical volume of average tree reached the maximum, indicating that the stand average tree reached the technical maturity; when the stand age was 22 years, the annual average quantity of technical volume of stand and the net benefits of management reached the biggest, implying that the stand economic maturity age was 22 years. Using the same method to calculate and determine the economic maturity age of the stands of different site index. The results were shown in Table 6.

**Table 5**
**Mature Process of Chinese fir forest of Site Index 16**

| Age/year | $V1/m^3$ | $V2/m^3$ | Net benefit/RMB/$hm^2$·year |
|---|---|---|---|
| 20 | 0.00527 | 6.177 | 3460 |
| 21 | 0.00545 | 6.199 | 3487 |
| 22 | 0.00561 | 6.201 | 3497 |
| 23 | 0.00575 | 6.182 | 3490 |
| 24 | 0.00587 | 6.151 | 3472 |
| 25 | 0.00597 | 6.101 | 3440 |
| 26 | 0.00605 | 6.035 | 3396 |
| 27 | 0.00612 | 5.961 | 3345 |
| 28 | 0.00617 | 5.882 | 3290 |
| 29 | 0.00621 | 5.795 | 3229 |
| 30 | 0.00624 | 5.695 | 3159 |
| 31 | 0.00625 | 5.596 | 3089 |
| 32 | 0.00626 | 5.494 | 3016 |
| 33 | 0.00625 | 5.390 | 2943 |
| 34 | 0.00624 | 5.279 | 2864 |
| 35 | 0.00622 | 5.169 | 2786 |

In Table 5, Age-stand age, *V*1—Annual average quantity of technical volume of the average tree, *V*2—Annual average quantity of technical volume of stand, Net benefit—Annual average net benefits of stand.

**Table 6**
**The Maturity Age of Chinese Fir Plantation of Different Site Index**

| Index | Tree maturity age | Stand maturity age | Economic maturity age |
|---|---|---|---|
| 12 | 26 | 22 | 23 |
| 14 | 30 | 22 | 23 |
| 16 | 32 | 22 | 22 |
| 18 | 35 | 22 | 22 |
| 20 | 35 | 23 | 23 |

In Table 6, index—stand site index, tree maturity age—technical maturity age of average tree, stand maturity age—technical maturity age of stand, economic maturity age- economic maturity age of stand.

### 2.3 The Best Final Felling Age

The Table 6 revealed the stand average tree technical maturity ages of different site index were distinctly different .The higher the site index of stand, the greater the technical maturity age of stand average tree. The gap between the maximum and the minimum of maturity age was up to 9 years. The difference of standing technical maturity ages of different site index was very small, only one year. The difference of standing economic maturity ages of different site index was small also. The range of stand economic maturity ages was between 22 and 23 years.

## DISCUSSION

Comprehensive use of the analytical data of average tree of sample plots and subcompartment data of forest management inventory, we analyzed the growth process of tree and forest stand and obtained the data of growth process of stand average tree and of the stand plant density which is similar with the data achieved by establishing the fixed sample plots to do regular surveys for decades. On the basis of the data, we established the related function models and determined the best final felling age of Chinese fir plantation, which can greatly save time and manpower and increase efficiency of the research. The density variation function model of standing plants is built to accurately reflect the actual situation of operation and management of Chinese fir plantation. We determined the final felling age, which will provide a scientific basis of management decisions for forest managers and forestry administrative departments.

## CONCLUSION

According to the data of analytic trees, we established the average tree growth process models of Chinese fir plantation with different site index. We worked out the technology available minimum ages of the various kinds of technical volume of stand average tree and the age when the annual average growth of technical volume reaches the maximum. Utilizing the investigation subcompartment data of Chinese fir plantation, we built the stand plant density model, researched the technical volume growth process and draw the following conclusions:

(a) Chinese fir technology available minimum age reduces with the increase of site index. The technology available minimum ages of different species wood are obviously different. For the average tree of Chinese fir plantation with site index 12-20, the range of the minimum age available for technology of the technical wood with 4 cm the diameter at small end and 4 m the length is between 7.5 and 12.1 years. For the technical wood with 6 cm the diameter at small end and 4 m the length, the range of the minimum age available for technology is between 8.9 and 13.8 years. For the technical wood with 4 cm the diameter at small end and 6 m the length, the range of the minimum age available for technology is between 9.0 and 14.5 years. For the technical wood with 6 cm the diameter at small end and 6 m the length, the range of the minimum age available for technology is between 10.6 and 16.7 years.

(b) The technical maturity age of average tree of Chinese fir plantation enhances with the increase of site index. The technical maturity ages of the average tree of Chinese fir plantation with site index 12, 14, 16, 18, 20 are respectively 26, 30, 32, 35, 35 years, which are higher than the minimum age available for technology for different purposes of Chinese fir plantation.

(c) The plant density of Chinese fir plantation decreases with aging. The average plant density of Chinese fir plantation is 2,763 plants/hm$^2$ at the fifth year and declines year by year with aging. The density reduces to about 1,100 plants/hm$^2$ when the Chinese fir trees reach final felling.

(d) There is no obvious difference between economic maturity ages of Chinese fir plantation with different site index. So we suggest the final felling age of Chinese fir plantation is 22 years, which are 6 years later than the final felling age of Chinese fir regulated by Guangxi Forestry Department and 3 years earlier than the final felling age determined by State Forestry Administration.

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