width, minimum seed width, seed length and seed weight with R^2 value of 0.366 (Jayasankar *et al.,* 1999). In case of *Grewia optiva,* the seed length and the 100 seed weight were found to be the best predictors of germination (Tyagi *et al.,* 1999).

From the above study it is concluded that the drupe and germination characteristics exhibits large variability. The Mudumalai seed source was the biggest and the Parambikulam was the heaviest. The Nilambur source had both high filling and germination percentages. The average percentage of empty, one, two, three and four seeded fruits were 37, 43.9, 15.3, 3.4 and 0.5% respectively. The filling percentage increases with weight of drupe and can be predicted using linear regression equation. The mesocarp and D/S weight plays major role in germination. The germination percentage can be predicated using D/S weight fitting in a polynomial equation. Among one, two, three and four seeded fruits, the germination percentage was observed to increase with increase in percentage of two seeded drupes.

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Pollen Dispersal and its Spatial Distribution in Seed Orchards of *Cunninghamia lanceolata* (Lamb.) Hook

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Abstract

Data from three seed orchards (Chongyang, Zhangle and Laoshan) and Lintian forest of Chinese fir was used to study pollen dispersal and its spatial distribution. The results show that the pollen dispersal has its own release pattern and day-night cycle. Vertical pollen distribution is as a cluster one; Horizontal pollen distribution in seed orchards and in normal forest is a uniform distribution type. Outside seed orchards and normal forest pollen distribution is diffusible. Wind speed is the most important factor for pollen dispersal. The relationship between pollen amount and distance to a seed orchard is linear. Based on the characteristics of pollen dispersal, methods for the management of artificial pollinate during the pollen dispersal season have been developed.

Key words: Cunninghamia lanceolata (Lamb.) Hook/Chinese fir, seed orchard, pollen dispersal, spatial pollen distribution.

A seed orchard is constructed with clones of superior trees in order to produce high quality seeds. To select superior trees

Table 1. – The details of seed orchards and the Lintian forest.

Stand	Location	Area m^2	Clone number	Age (years)	Height m	BHD cm	Latitude	Longitude	Elevation m
ChongyangS.O	Hillside	80000	32	5 to 9	6.39	10.42	29° 38′ 27″	114° 8′ 19″	148 to 226
Laoshan S.O	In Qiandao Lake	311350	620	10 to 13	6.03	11.61	29° 34′ 56″	118° 52′ 24″	100 to 305
Zhangle S.O	Hillside	342838	657	10 to 14	6.74	12.04	30° 16′ 32″	120° 12′ 28″	64 to 150
Lintian forest	Hillside	800000	0	18	8.71	16.21	30° 22′ 12″	119° 47′ 8″	50 to 120

and establish a seed orchard are very important steps during normal tree breeding. According to the information from Chinese fir Seed Orchard Research Group, the volume of 3 to 12 year old trees from 337 clones is from 37.8% to 81.6% more than that of unimproved forest (SHEN XIHAN, 1990). The seed orchard plays a very important role in tree breeding because of its early and stable seed production to produce high quality seeds.

Chinese fir is a very important timber tree because of its characteristics of fast growth, high quality timber and widely use in southern China. The numbers of pollen and ovules, pollen components and pollen spatial distribution determine the production and quality of hybrid seeds. In order to predict seed production and manage the seed orchard scientifically, we studied pollen dispersal, spatial pollen distribution based on data from tree seed orchards (Chongyang, Zhangle and Laoshan) and the Lintian forest.

Materials and Methods

1. Seed orchards and the Lintian forest used in this study

We carried out the research in three seed orchards (Chongyang, Zhangle and Laoshan) and Lintian forest. The details of seed orchards and Lintian forest show in *Table 1*.

2. Material and method

We used collectors to obtain pollen samples in the air, the collector was built with bottom board and cover board (15 by 15 cm^2, and 10 cm apart), and two board was nailed on two wood sticks (1 × 1 × 10 cm). It was ventilation in each direction. Before we fasted slide glasses at proper place of pollen collectors we sized slide glasses with a little bit Vaseline in order to stick pollen in the air. And we measured the temperature, relative humidity, wind speed and atmospheric pressure at the same time when we fetched slide glasses. We counted the pollen in 5 views under microscope for a slide glass (ZHANG ZHUOWEN et al., 1990, 2001).

With 1 slide glass the 24 h-pollen-collectors were put in different direction, different topography and different height in each seed orchard and Lintian forest equally, and the pollen collector was 1.5 m high from the ground. According to the area of seed orchards or forest, the number of pollen collector could be 10 to 50. We fetched the samples at 8 to 10 a.m. every day during pollen dispersal. We put 3 to 8 collectors with 8 slide glasses in 8 directions in each seed orchard and Lintian forest.

We set 3 to 5 vertical plots in each seed orchard and Lintian forest as well. Each vertical plot had 6 pollen collectors (each collector with 1 slide glass) at 0/2H, 1/2H, 2/2H, 3/2H, 4/2H and 5/2H. H here is the mean height of trees to be studied. We fetched slide glasses at 6, 8, 10, 12, 14, 16, 18, 22 and 2 O'clock. We connected these 6 collectors with a rope and passed the rope through a wheel fixed on an enough height bamboo trunk staked at the plot site, in this way we could easy operate to fetch slides. We repeated 3 to 5 times of day-night for this vertical pollen test during dispersal in a seed orchard or forest.

With Microsoft Excel and SPSS we dealt with data from research. We found the relationships between spatial pollen distribution and height, distance, etc. by means of linear, logarithmic, exponential, power, quadratic regression (LU WENDAI, 2000). We also found the relationship between pollen dispersal and meteorological factors by means of stepwise regression (FU WUYU and CHNG HUHANG, 1980; LU WENDAI, 2000). The pollen distribution pattern was determined by the distribution index, I = D/X, I here with no unit is distribution index, D variance and X average.

Result and Discussion

1 The day-night and date cycle of pollen dispersal of Chinese fir

1.1 The date cycle of pollen dispersal of Chinese fir

Male cones of Chinese fir release pollen from March to April every year, but the starting date, duration and the end date are determined by its geographic location, such as longitude, latitude, altitude and the environment of the seed orchard or forest. Trees in the Laoshan seed orchard began to disperse pollen from March 14 to 16 and end from April 14 to 17. The dispersal duration lasted about one month because the seed orchard was located at Laoshan Island in Qiandao Lake. To contrast Laoshan seed orchard, Chongyang, Zhangle seed orchards and Lintian forest start to release pollen from March 19 to 24, and end from April 5 to 15, and the pollen dispersal durations were much shorter than that of Laoshan seed orchard. CHEN XIAOYANG (1991) got the same conclution. The longer the duration of pollen dispersal, the greater probability for good fertilization.

The pollen quantity in the air during pollen dispersal is determined by age and density of the trees in seed orchard or stand. The pollen quantity of Laoshan, Zhangle, Chongyang seed orchards and Lintian forest are 697, 316, 133 and 282 grain/cm^2. d^{-1} respectively (*Figure 1*).

In order to test the differences in pollen quantity among seed orchards and forest every day during dispersal we used analy-

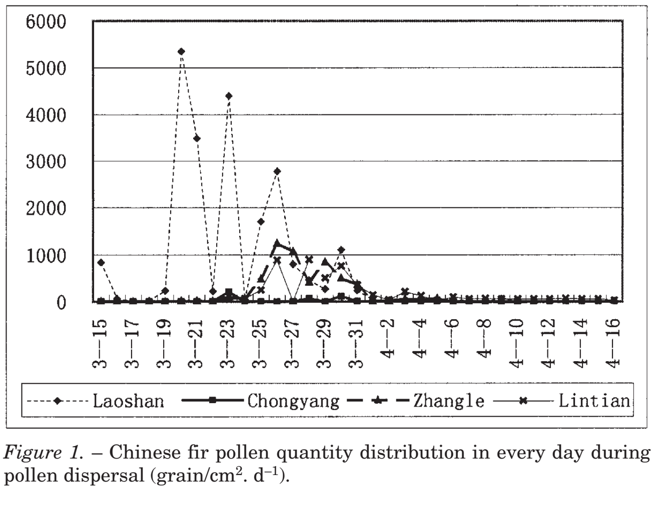

Figure 1. – Chinese fir pollen quantity distribution in every day during pollen dispersal (grain/cm^2. d^{-1}).

Table 2. – The analysis of variance of pollen quantity among Laoshan, Zhangle, Chongyang seed orchards and Lintian forest.

Variance origin	Df	Sum of squares	Mean square	F	$F_{(3,128)}$ 0.01
Between groups	3	7803902	2601301	5.1780**	3.93
Within group	128	64292056	502281.7		
Total	131	72095958			

Table 3. – The analysis of variance of pollen quantity among dates in the Laoshan seed orchard.

Variance origin	df	Sum of squares	Mean square	F	$F_{(31,256)}$ 0.01
Between groups	31	164688.2708	5312.5249	14.5836**	2.07
Within group	256	93256.4772	364.2811		
Total	287	257944.748			

Table 4. – The analysis of variance of pollen quantity between both time of day-night and height in Laoshan seed orchard (March 24 to 25).

Variance origin	df	Sum of squares	Mean square	F	$F_{(8,40)}$ 0.01
Day-night time	8	2148.7489	268.5936	10.68**	5.12
Height	5	663.0681	132.6136	5.27**	
Error	40	1006.3606	25.159		
Total	53	3818.1776			

sis of variance. The results show that the difference among seed orchards and forest is very clear. The differences among dates is very clear as well. To take Laoshan seed orchard as an example (*Table 2* to *3*).

1.2 The day-night cycle of pollen dispersal of Chinese fir

The pollen dispersal appears to vary because of the changes in temperature, relative humidity, atmospheric pressure and wind speed. In the day-night cycle of pollen dispersal, the minimum pollen quantity occurs at 22 to 2 o'clock, the maximum at 10 to 12 o'clock, and the second peak at 14 to 18 o'clock. The analysis of variance of pollen quantity shows the difference among times is very clear. Because the data from all three seed orchards and forest have the same pattern, we used Laoshan as an example (*Table 4* and *Figure 2*). And *Figure 2* is based on the data of 36 day-night measurements.

2 Spatial pollen distribution during release in Chinese fir

2.1 Vertical pollen distribution during release in Chinese fir

Vertical pollen distribution during release in Chinese fir in Laoshan, Zhangle, Chongyang seed orchards and Lintian forest are all the same, so we can describe this distribution as an average of above 36 data sets. The analysis of variance shows the pollen quantity differences among the different heights is very clear (*Figure 3* and *Table 4*).

Using the data of height and pollen quantity (*Figure 3*), we obtained a quadratic regression equation ($N = 199.76265 + 10.51188H-27.78267H^2$, Multiple R = 0.9624, F = 18.8101, Signif. F0.0201, N here is pollen number, and H height), and this equation is statistically significant. H here is the height of average of trees (in m).

The mean pollen quantity of different height is 148.9 grain/$cm^2.d^{-1}$, variance 155.4, and the index of distribution I = 1.04 >1, It belongs to cluster distribution type.

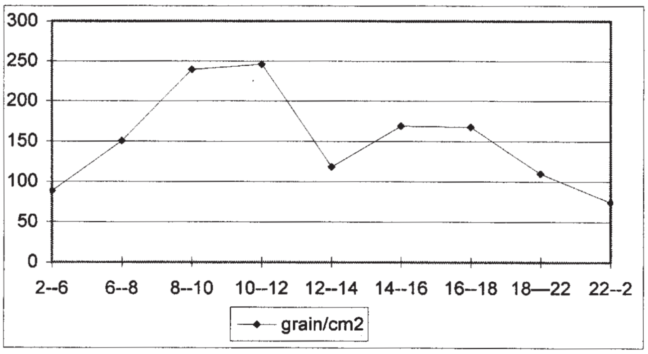

Figure 2. – Chinese fir pollen quantity distribution in day-night cycle.

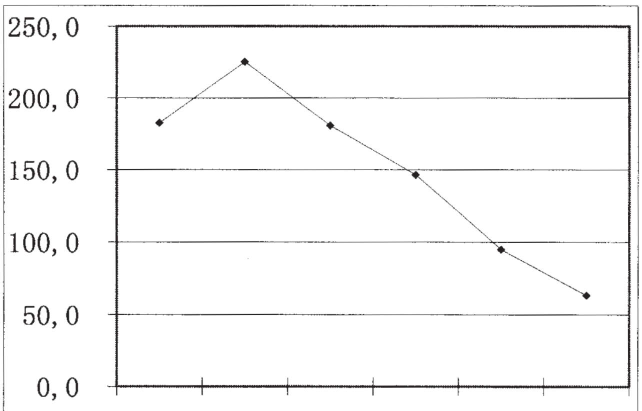

Figure 3. – Vertical pollen distribution during release in Chinese fir seed orchards.

Table 5. – Analysis of variance of the regression equation significant.

Model	Sum of squares	Df	Mean square	F	Sig.
Regression	8625573.665	1	8625573.655	5.25*	0.029
Residual	49284732	30	1642824.409		
Total	57910306	31			

2.2 Horizontal pollen distribution during release Chinese fir

A. Pollen quantity in different directions: The result of analysis of variance shows that the differences in pollen quantity among 8 directions is not clear.

B. Pollen quantity in different plots in a seed orchard or forest: The result of analysis of variance shows that the pollen quantity differences among plots in a seed orchard or forest is not clear. Laoshan, Zhangle, Chongyang seed orchards and Lintian forest produce the same results. The indexes of pollen distribution of Laoshan, Zhangle, Chongyang seed orchards and Lintian forest are 0.07, 0.06, 0.02 and 0.10 respectively, and they belong to even distribution type because $I < 1$. This result maybe caused by wind.

C. Pollen quantity of different plots outside a seed orchard: The pollen quantity outside a seed orchard is determined by the pollen quantity in the seed orchard, the distance from seed orchard, topography, wind speed and wind direction. The pollen distribution type is that the pollen diffuses from a seed orchard or forest to outside, the pollen number and the distance from a seed orchard or forest follows the relationship: $N = 1533.60–2.68L$, $R = –0.96^{**}$, N here is pollen number, and L distance from seed orchard. Therefore we should keep an isolation distance of 600 to 1000m for a Chinese fir seed orchard in order to isolate it from outside pollen. CHEN XIAOYANG (1996) got the same conclution.

3 The relationship between pollen dispersal and meteorological factors

The pollen dispersal of Chinese fir is controlled by the meteorological factors, such as temperature, relative humidity, air pressure and wind speed. With data from Laoshan seed orchard we analyzed the pollen quantity and meteorological factors by means of stepwise regression, the result shows that wind speed is the most important factor on pollen dispersal. So we got the relationship: $N = 9.298 + 1397.882V$, multiple $R = 0.888^{*}$, N here is pollen number, and V wind speed (*Table 5*).

In general, wind speed is a very important factor for pollen dispersal, but temperature is sometimes also an important factor.

4 The management of pollination in a seed orchard of Chinese fir

Although the pollen quantity and its distribution both in vertical and horizontal space are very good for pollination and fertilization in Chinese fir seed orchard, it is sometimes necessary to pollinate by man due to meteorological factors. Therefore we have developed guidelines for artificial pollination in a seed orchard of Chinese fir.

(1). Collect pollen: At 10 to 15 o'clock on a fine day, pollen is collected by following ways,

a. Just before the male cones dispersal, to cover these cones with a bag and to shark the twig.

b. To cut twigs before pollen dispersal and place them in water in a closed room, then put the container with twigs on a piece of paper. When sac opens, pollen falls on this paper.

(2). To desiccation pollen: Put pollen in a 500 ml clean bottle, fill only half of a bottle. Put the bottle half filled with pollen into a desiccator during desiccating. The result shows that water content is the most important factor to maintain pollen viability. The water content should be less than 10 %.

(3). To store pollen: Put sealed bottles with pollen into a refrigerator. The temperature should be 0 to 5 °C. if we want to keep pollen living longer, use –5 to 0 °C.

(4). Artificial pollination: When female cones open we can spray pollen with sprayer at 10 to 16 o'clock in a fine day, and pay attention to the topography and the direction of wind. If pollen is limited we can mix pollen with talcum powder before spraying, but never spray pollen with water, because water can kill pollen.

Conclusion

The pollen quantity is determined by tree age and density. The quantity difference among seed orchards and nature forest is very clear. Pollen dispersal can be divided into 3 stages, the early, mid and late stage. The pollen quantity difference among dates is very clear. The pollen quantity of day-night cycle shows that the minimum appears at 22 to 2 h, the maximum at 10 to 12 h, and the second peak at 14 to 18 h, and the difference of pollen quantity among time of day-night is very clear.

The pollen vertical distribution type is a cluster one. The pollen quantity and height appears to be a quadratic regression ($N = 199.76265 + 10.51188H–27.78267H^2$), and the difference of pollen quantity among the different height is clear. The pollen distribution in seed orchards and forest horizontally space belongs to an even distribution because of $I < 1$. Pollen number and the distance from a seed orchard or forest follows the equation: $N = 1533.60–2.68L$. We should maintain an isolation distance of 600 to 1000 meters for a Chinese fir seed orchard in order to protect it from outside pollen.

Wind speed is entered regression equation and temperature, relatively humidity and air pressure are removed by means of stepwise regression: $N = 9.298 + 1397.882V$.

Artificial pollination is a normal practice for management of a seed orchard. This includes pollen collection, pollen desiccation, pollen storage, and artificial pollination. The water content is the most important factor and the temperature secondly to maintain pollen viability during storage. We can never spray pollen with water, or pollen will been killed.

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Earlywood-Latewood Demarcation Criteria and Their Effect on Genetic Parameters of Growth Ring Density Components and Efficiency of Selection for End-of-Rotation Density of Radiata Pine

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Abstract

Most commonly used components of the basic density of a growth ring are earlywood density, latewood density and latewood ratio. Various arbitrarily chosen criteria have been used as a demarcation of the earlywood-latewood boundary. The present study was conducted to compare genetic parameter estimates of ring density (RD) components using various demarcation criteria. Three criteria were considered: density of 400 kg/m^3 as a threshold; the average of the minimum and maximum density within the ring; two-thirds of the difference between the minimum and maximum density within the ring. Relative efficiency of selection using ring density and its components as selection criteria, for improving the average ring density at harvest age, was also evaluated. A pith-to-bark 5-mm increment core was taken from each of 8 or 9 trees from each of 50, 30-year-old, open-pollinated radiata pine families. Averages across each core, weighted according to ring width, were determined for overall RD, earlywood density, latewood density and latewood ratio, defined according to the above criteria.

Estimated individual-tree heritability of RD at ages 5 and 10 years were 0.71 and 0.81 respectively. Estimates of heritability and genetic correlations among growth ring density components varied considerably depending upon the demarcation criteria. The combination of low estimated heritability of latewood ratio and its non-significant genetic correlations with other traits argues strongly for discounting this variable for not contributing much information. Relative efficiencies of family selection for age-30 RD, based on RD at core ages 5 and 10 years as selection criteria, were calculated to be 82 and 93 percent, respectively. Index selection, involving ring density and its components, appeared to improve selection efficiency. Using the average of the lowest and highest density within a ring as the demarcation criterion gave the highest apparent relative efficiency of family selection. However, increased efficiencies of combined selection on densitometer-measured traits may not be worth the extra costs above selection for density of whole cores.

Key words: Ring density, heritability, family selection, genetic correlation, correlated response, index selection, *Pinus radiata*.

Introduction

Wood basic density is probably the most important indicator of wood quality because of its important role in determining wood strength and stiffness, pulp digester yield and several other wood properties. Understanding the genetics of wood density is complicated by the composite nature of this trait. The wood produced early versus late in the annual growing season is termed as earlywood (EW) and latewood (LW) respectively (ZOBEL and JETT, 1995). Earlywood is formed when there are high auxin levels but the amount of photosynthesis available for cell wall formation is limiting (ZIMMERMAN and BROWN, 1971). Compared with LW, EW has shorter, wider tracheids with thinner cell walls while darker band of cells with longer, thicker-welled cells, in the outer part of the growth ring is referred to as being LW (ZOBEL and JETT, 1995).

The X-ray densitometry method (COWN and CLEMENT, 1983), which enables continuous records of density from pith-to-bark, is widely used for such ring by ring determination of wood density. The resulting cyclic density profiles are described in terms of minimum, maximum, earlywood and latewood density, latewood ratio and the average ring density. Because of the difficulty posed by EW intergrading with LW, various arbitrarily chosen thresholds (e.g. COWN and BALL, 2001) have been used to demarcate EW from LW.

A particular value of ring density (RD) can result from various combinations of its component traits and knowledge of the genetic control of these component traits may help in understanding the genetics of overall wood density. The most commonly used components of RD are earlywood density, latewood density and latewood ratio. Genetic control of RD components has been widely studied in various species including *Pinus radiata* (NICHOLLS et al., 1980; COWN and BALL, 2001), *Pinus sylvestris* (HANNRUP, 1999), *Pinus caribaea* (HARDING et al., 1991), *Pinus densiflora* (OHTA, 1989), *Picea abies* (WORRALL, 1975; HYLEN, 1999), *Picea mariana* (ZHANG and MORGENSTERN, 1995; ZHANG, 1998), *Pseudotsuga menziesii* (VARGAS-HERNANDEZ and ADAMS, 1991), Cryptomeria japonica (FUGISAWA et al., 1993) and *Eucalyptus nitens* (GREAVES et al., 1997). Different authors have used different demarcation criteria for EW and LW boundaries. Three main methods of determining the transition point have been used: first, an arbitrary threshold of wood density, say, 400 kg/m3 in radiata

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