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EFFECTS OF SILVICULTURAL PRACTICE, TREE, CAMBIAL AGE AND HEIGHT ON WOOD DENSITY COMPONENTS OF PLANTATION POPLAR I-69 (*POPULUS DELTOIDES* CV. I-69/55) IN CHINA

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In the study, the testing material of 6 trees of poplar clone I-69 (*Populus deltoides* CV. I-69/55) trees aged 12 years old were selected from the stands which located on the bank of Yangtse River in Tianchang city, Anhui province, China. The wood density components (overall wood density (WD), earlywood density (DEW), latewood density (DLW) and relative wood density (DMax-DMin and DLW-DEW)) were measured using microdensitometry methods. The effect of silvicultural practice, tree, cambial age and height of tree on wood density components was analyzed respectively. The results are as follows:

1. The effect of silvicultural practice on wood density is significant at the 1% level, but not significant on earlywood density, latewood density and relative wood density.
2. The tree effect on wood density, earlywood density, latewood density and relative wood density is not significant.
3. The cambial age effect on wood density is significant at the 5% level, very significant on earlywood density, latewood density and relative density at the 0.1% level. There are large differences for radial variation patterns of wood density in 6 trees. In general, it has two kinds of radial variation patterns like increasing from pith to bark and decreasing outward at different heights. The wood density within a growth ring increases from earlywood to latewood continuously, but there exists large alteration when the cambial age is less than four years.
4. The height effect on wood density including earlywood density and latewood density is significant differently in different trees. The wood density in the bottom (below 2m) is lower than the upper one (above 2m). The DMax-DMin fluctuated heavily below 2m and above 5m, but the DLW-DEW increases from bottom to 2m height and levels off upward.

KEYWORDS

Plantation poplar I-69 (*Populus deltoides* CV. I-69/55); wood density components; variation patterns

INTRODUCTION

Plantation poplar with various clones is distributed widely and grows rapidly, which is regarded as one of the most important fast-growing plantation species. The clones selection, silviculture, processing and utilization on poplar were taken into account by the researches in the world and the International Poplar Commission (IPC) was formed specially in 1947. In China, the poplar

Sub-Commission was also founded in 1960s and many works, such as genetic breeding, optimization of silvicultural practice and introducing new clones from other country, had been done with high interest. It is estimated that more than twenty poplar clones, which growth fast and have superior characters for utilization, were bred or introduced in the last decade and the planting areas of poplar reach 6.66 million ha (Wang, 1995). Among this poplar clones, poplar I-69 (*Populus deltoides* CV. I-69/55), introduced from Italy in 1980s, is now widely distributed in the south areas of China and become one of the main clone for veneer and pulp industry owing to its rapid growth and proper wood quality. Although many literatures have focused on properties and utilization of poplar clone I-69, especially in wood veneer and paper industry (Li, 1982; Bao and Liu, 1999; Jiang and Sheng, 1998), there are still short of comprehensive understanding about wood quality variation originating from several factors, including different trees, cambial age, height of sampling wood and forest practice. The last one has a very distinguished instance that the vegetables and crops are planted under forest crown as inter-fillers in China.

Wood density is regarded as the single most important physical characteristic which directly affects the wood processing and utilization (Panshin and de Zeeuw, 1980; Haygreen and Bowyer, 1996). It is reported that there are large variation of wood density coming from different seed resource, clones and silvicultural practices, cambial ages and heights (Butterfield, *et al*, 1993; Szymanski, *et al*, 1991; Wright, 1993; Liu and Bao, 2001). Although some relationships between wood density and other properties and their variation pattern were well studied in different species such as trembling Aspen (Yanchuk, 1984), Green Ash (Lowe, 1990), red pine (Shepard, 1992), European aspen (Karki, 2001) etc., the wood density components variation patterns like overall wood density (WD), earlywood density (DEW), latewood density (DLW) and relative wood density (DMax-DMin and DLW-DEW) of different poplar clones are still short of report in detail.

In fact, wood density is combination of several wood properties and reflects the characteristics of wood laid down by cambial during a growing season: earlywood and latewood (Panshin and de Zeeuw, 1980). Besides the earlywood and latewood density, the minimum and maximum density each ring can influence the overall wood density. Therefore, knowledge of variation pattern of wood density components like overall wood density, earlywood density, latewood density and relative density

(DMax-DMin and DLW-DEW) is important in breeding strategies when it is desired to include wood quality traits in breeding programs (Hysten, 1999). In this paper, the effect of silvicultural practice, tree, cambial age and height on wood density components of poplar I-69 in China was studied using microdensitometry methods so as to provide more information for poplar breeding, silviculture and utilization.

MATERIALS AND METHODS

The testing materials of 6 trees of poplar clone I-69 (*Populus deltoides* CV. I-69/55) trees were selected from the stands which located on the bank of Yangtze River in TianChang city Anhui province China. The growth conditions and characteristics of 6 poplar trees were listed at Table 1. It shows that all the trees are 12 year old. The diameter of breast height ranges from 23.5 cm to 24.6 cm and the height of tree from 13.5 m to 15 m. Three trees, coded from 1 to 3, were fertilized when the inter-fillers were planted, and the left trees were kept as control. It grows in the river beach with sand soil. The average illumination time of year is 1800-2500 hours, the average temperature of year is 15.4°C to 16.6 °C, the no frost period is 220 days to 240 days and the average precipitation of year is 1041 mm (Zha and Liu, 2005).

The testing material was drawn according to Chinese National Standards of Physical and Mechanical testing methods of wood (GB 1927-1940-91). For each tree, discs with 5cm thickness for studying anatomical characteristics and

microdensity were chopped at five different heights (0-0.3 m, 1 m to 1.3 m, 2 m to 2 m, 3 m to 4m, 4 m to 6m) except the fifth tree (only 0.3 m, 1.3m) of 6 poplar trees respectively, logs with 2m length for studying physico-mechanical properties were saw above the breast height (1.3 m to 2 m and 2 m to 4 m), and logs with 1 m length for studying quality of veneer were saw under the breast height (0.3 m to 1.3 m). Each disc was cut into four segments from the pith to bark with 2 cm width and 1.5 cm height through the pith along the south and north direction (Figure 1). The first one of the segments (including the south one and the north one from pith) was used for measuring microdensity. Totally, 27 segments were obtained. These segments were then taken into France and put into the air-room with temperature of 20 C°, humidity of 65% until the moisture of content reaches 12%. Next, only one sample from south or north direction for each segment was selected for measuring microdensity in order to avoiding the knots and defects. Before scanning with x-ray, the samples were processed into the exact small testing samples with the thickness of about 1.8 mm and their radial length, weight and thickness were measured (Table 2). The whole measurement was done in l'EQUIPE QUALITE DES BOIS in Nancy, France. After scanning, the radiographer of each sample was obtained and CERD software was used to mark the ring and calculate the wood density automatically.

Table 1. The growth conditions and characteristics of six poplar trees

Sample no.	Age (year)	DBH (cm)	Height(m)		Silvicultural practices	Topography	Soil type	Average illumination of year (hours)	Average temperature of year (C°)	No frost period (day)	Average precipitation of year (mm)
			Total	Under branch							
1	12	24.5	14.5	7.8	Fertilized while planting inter-fillers	River beach	sand soil	1800-2500	15.4 to 16.6	220 to 240	1041
2	12	24.6	15.0	8.2							
3	12	23.5	13.5	6.4							
4	12	24.1	14.0	7.2	control						
5	12	23.9	13.8	6.7							
6	12	23.7	14.2	7.5							

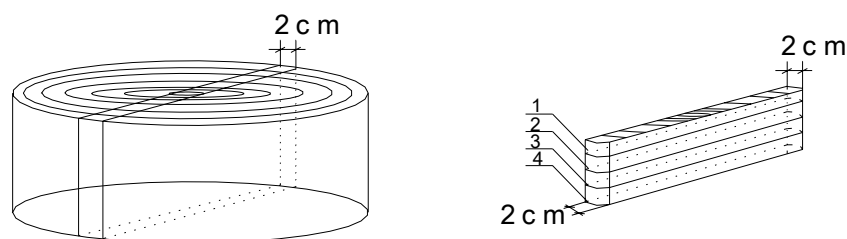


Figure 1. Sample sawing and distribution

Considering a given ring wood density profile, the software separates the earlywood and latewood by a specific density value, which calculated by the following formula:

$$Dt = k \cdot D_{\text{Min}} + (1-k) \cdot D_{\text{Max}},$$

where D_{Min} and D_{Max} are the minimal and maximal values of the ring profile,

k is a constant usually equal to 0.5 (except for European oak, where a k value of 0.8 was found to better fit anatomical measurements).

Here, 20 density values from Earlywood to Latewood were gotten in each growth ring and their variation patterns of average wood density, Earlywood density (DEW), Latewood density (DLW) and relative density (DLW-DEW and $D_{\text{Max}} - D_{\text{Min}}$) of 6 trees at 5 heights under two silvicultural practices were obtained through analyzing.

RESULTS AND ANALYSIS

Effect of silvicultural practice on wood density variation of poplar I-69

The methods for improving wood quality come from forest genetic and silviculture. The scientific silvicultural treatment includes planting density (space), fertilization, thinning, pruning and irrigation (Ke, 1980), but the silvicultural practice for poplar growing in the river beech in China only includes planting inter-fillers due to economical causes. Thus, the planting tree was indirectly treated while planting inter-fillers with fertilization and soil treatment. Table 3 shows the difference of wood density of 6 poplar trees between the silvicultural practice and the control.

Table 2. The selected samples and parameters for microdensity measurement in 6 trees at 5 heights

Selected samples No.	tree	Height (m)	Direction N-north, S-south	Radial length(mm)	Weight (g)	Thickness (mm)
01-0N	1	0.3	N	150	1.0773	1.87
01-1S	1	1.3	S	131	0.9786	1.85
01-2N	1	2	N	119	0.9006	1.87
01-3N	1	4	N	96	0.7927	1.85
01-4N	1	6	N	110	0.8055	1.85
02-0N	2	0.3	N	140	1.1163	1.87
02-1N	2	1.3	N	119	0.9147	1.86
02-2N	2	2	N	124	1.0528	1.86
02-3S	2	4	S	116	0.9672	1.86
02-4S	2	6	S	101	0.751	1.86
03-0S	3	0.3	S	161	1.1475	1.85
03-1N	3	1.3	N	136	1.1342	1.87
03-2N	3	2	N	123	0.9801	1.86
03-3N	3	4	N	95	0.676	1.85
03-4N	3	6	N	97	0.7277	1.85
04-0S	4	0.3	S	160	1.4153	1.87
04-1N	4	1.3	N	126	0.9461	1.85
04-2N	4	2	N	108	0.8588	1.86
04-3N	4	4	N	97	0.6986	1.86
04-4N	4	6	N	96	0.7669	1.86
05-0S	5	0.3	S	154	1.0834	1.85
05-1S	5	1.3	S	126	0.9535	1.86
06-0N	6	0.3	N	161	1.2032	1.87
06-1N	6	1.3	N	132	1.2417	1.87
06-2N	6	2	N	115	0.8007	1.86
06-3N	6	4	N	94	0.7775	1.85
06-4N	6	6	N	90	0.6914	1.86

Table 3. Wood density, earlywood and latewood density in 6 trees under two silvicultural practices

Wood properties	Silvicultural practice				Control			
	1	2	3	average	4	5	6	average
Wood density (g/cm ³)	480.4	486.0	488.2	484.9	502.1	504.6	485.9	497.5
CV(%)	6.0	5.9	5.9	5.9	8.1	8.9	6.6	7.9
Earlywood density (g/cm ³)	446.0	451.2	458.5	451.9	465.9	460.5	451.6	459.3
CV(%)	8.7	6.8	7.6	7.7	9.2	9.4	8.5	9.0
Latewood density (g/cm ³)	549.9	572.4	564.0	562.1	582.6	571.1	570.6	574.8
CV(%)	11.9	10.0	10.8	10.9	13.6	9.8	11.6	11.7

It shows that the mean values and coefficient of variance of wood density, earlywood density and latewood density with silvicultural practice are lower than the control;

(484.9 g/cm³ < 497.5 g/cm³, 5.9% < 7.9%;

451.9 g/cm³ < 459.3 g/cm³;

7.7% < 9.0%;

562.1 g/cm³ < 574.8 g/cm³;

10.9% < 11.7%).

It indicates that the wood density, including earlywood density and latewood density, was decreased by the silvicultural practice treatment. Variance of analysis (Table 4) shows that the effect of silvicultural practice on wood density of poplar I-69 is significant at the 1% level, but not significant on earlywood density, latewood density and relative wood density.

Tree effect on wood density variation of poplar I-69

The variation of wood properties comes from many factors, such as species, individual tree, position in the tree, growth condition, under different forest practice and so on (Zoble and Buijtenen, 1989). All the average value and coefficient of variance, which was measured and calculated from testing materials, including earlywood density, latewood density and wood density, was listed in Table 3. From the table, it was concluded that the mean value and coefficient of latewood density are higher than earlywood, and the comparison between two different silvicultural practices is faintness. Variance analysis (table 4) shows that the tree effect on wood density components of poplar I-69 is not significant.

Cambial age effect on wood density of poplar I-69

Inter-ring variation of wood density

Figure 2 shows that radial variation pattern of wood density is assorted and can be altered by different trees and heights, which the disc was sawn out. The detailed pattern as following: wood density

Table 4. Variance of analysis of wood density, earlywood density, latewood density and relative density from different factors

Factors		Wood density	Earlywood density	Latewood density	DMax-DMin	DLW-DEW
Sivlicultural treatment		**	-	-	-	-
Tree	sivlicultural treatment	-	-	-	-	-
	control	-	-	-	-	-
Cambial age		*	***	***	***	***
Height	Tree 1	*	**	***	-	-
	Tree 2	**	**	-	-	-
	Tree 3	-	*	***	-	-
	Tree 4	-	-	-	-	-
	Tree 5	-	-	-	-	-
	Tree 6	*	***	-	-	-

Note: - not significant, * significant at the 5% level, ** significant at the 1% level, *** significant at the 0.1% level

increased from pith to park in tree 03, 04 and 06 through all heights, however, it decreases outward in tree 01. In terms of tree 02 and 05, there are more than two different variation patterns in each tree owing to varied heights, e.g. in tree 05, it increases from pith to bark at 0.3 m height, but decreases at 1.3 m height.

Different heights

The general radial variation of average DMax-DMin values of 6 trees at different heights (Figure 3) shows that the DMax-DMin in each ring fluctuates frequently in young ages (before the 8th years) and keeps stable after that. It indicates that the poplar I-69 in young ages is easily affected by around environments and silvicultural practices and its wood density is changed very largely in the growth season per year. It was also found that the DMax-DMin increases roughly with the height of the tree between the 8th and 13th year. It illustrated that the wood, which is close to the bark, has less homogenous density in the upper part of stem than the lower one. However, from the first growth ring to eighth, the relative density fluctuated irregularly along different height and the general variation pattern can not be concluded in this area, especially at 0.3 m and 1.3 m.

The radial variation pattern of DLM-DEW (Figure 3) is different from that of DMax-DMin and the curve ranging from fifth to thirteenth growth ring is similar with each other among different heights, except at 0.3 m and 0.6 m.

Variance of analysis (table 4) shows that cambial age effect on wood density is significant at the 5% level, cambial age effect on earlywood density, latewood density and relative density is significant at 0.1% level.

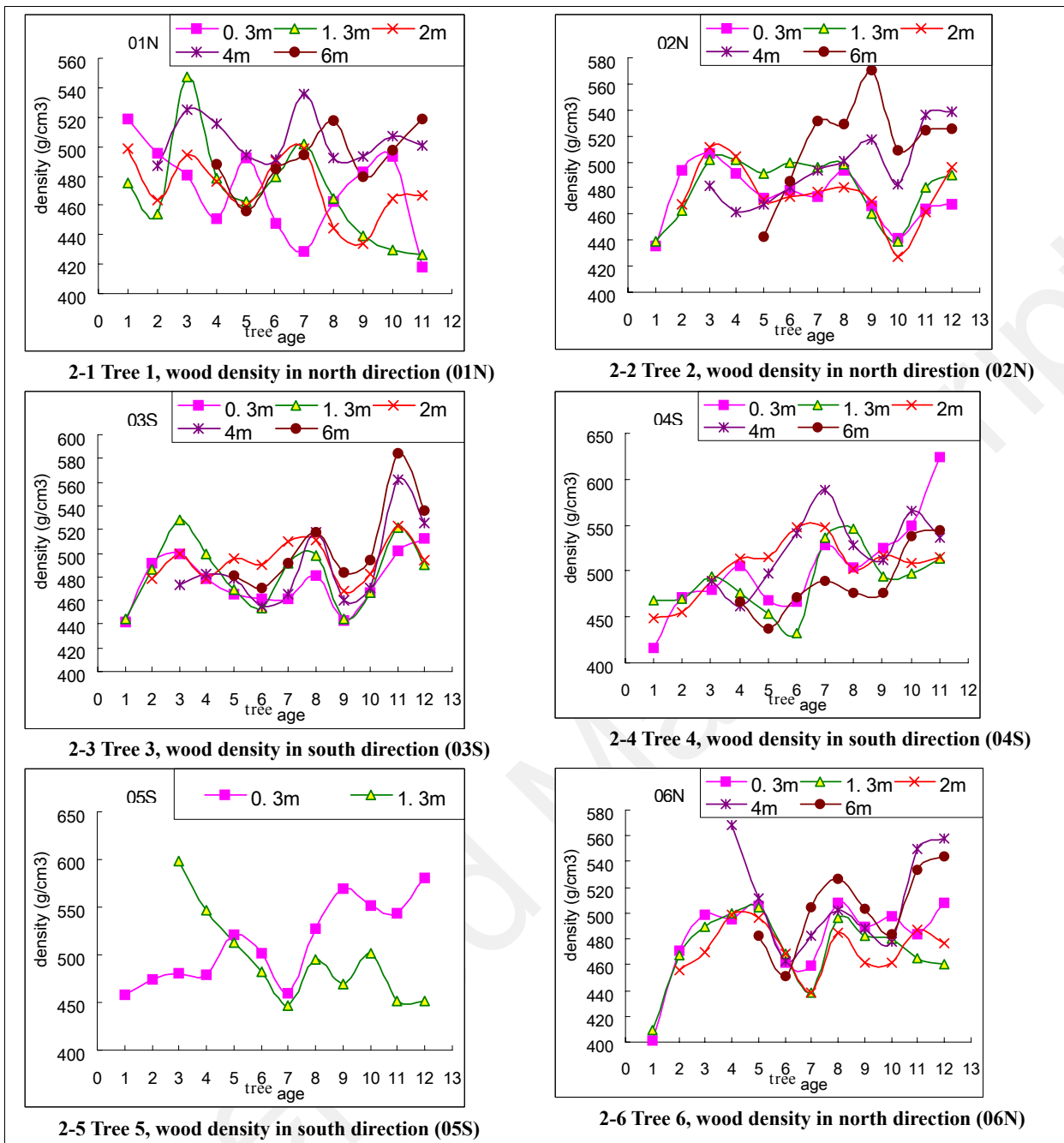


Figure 2. Radial variation of wood density in 6 poplar trees

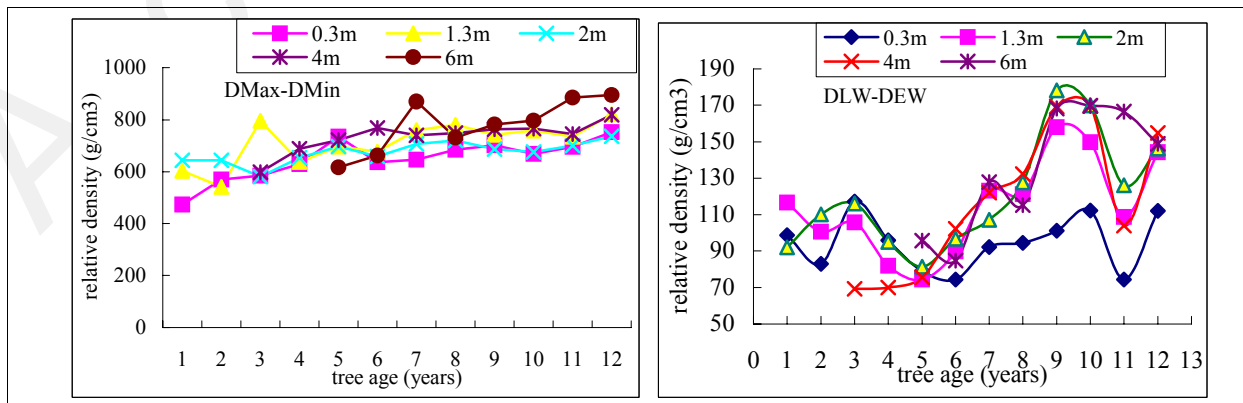


Figure 3. The radial variation of average relative density (DMax-DMin and DLW-DEW) of six trees at Intra-ring variation of wood density

It is interesting to know how the wood density varies from spring to autumn in one year. The wood density within a growth ring is considered as a criterion for studying the climate change of one year, but the wood density within a growth ring is not easy to obtain if using the ordinary methods. Microdensity is a very useful method to record the wood density changes within the growth seasons (Mothe *et al.*, 1998). Figure 4 shows the density variation within the growth rings (from the 1th year to the 12th year) at 1.3 m height of 6 poplar trees. It indicates that large alteration of wood density within a growth ring can be found when the cambial age is less

than four years, however, the change is dying away after the fourth ring and the density is increasing followed the rise of distance within ring. It also can be concluded that wood density increases from earlywood to latewood, which is distinguished according the formula stated above. This phenomenon was partly due to fertilization while planting inter-fillers in poplar stands and environmental variability like annual variations of the weather and flooding in summer. This result is corresponding with the wood density of variations of young Norway spruce (Danborg, 1994).

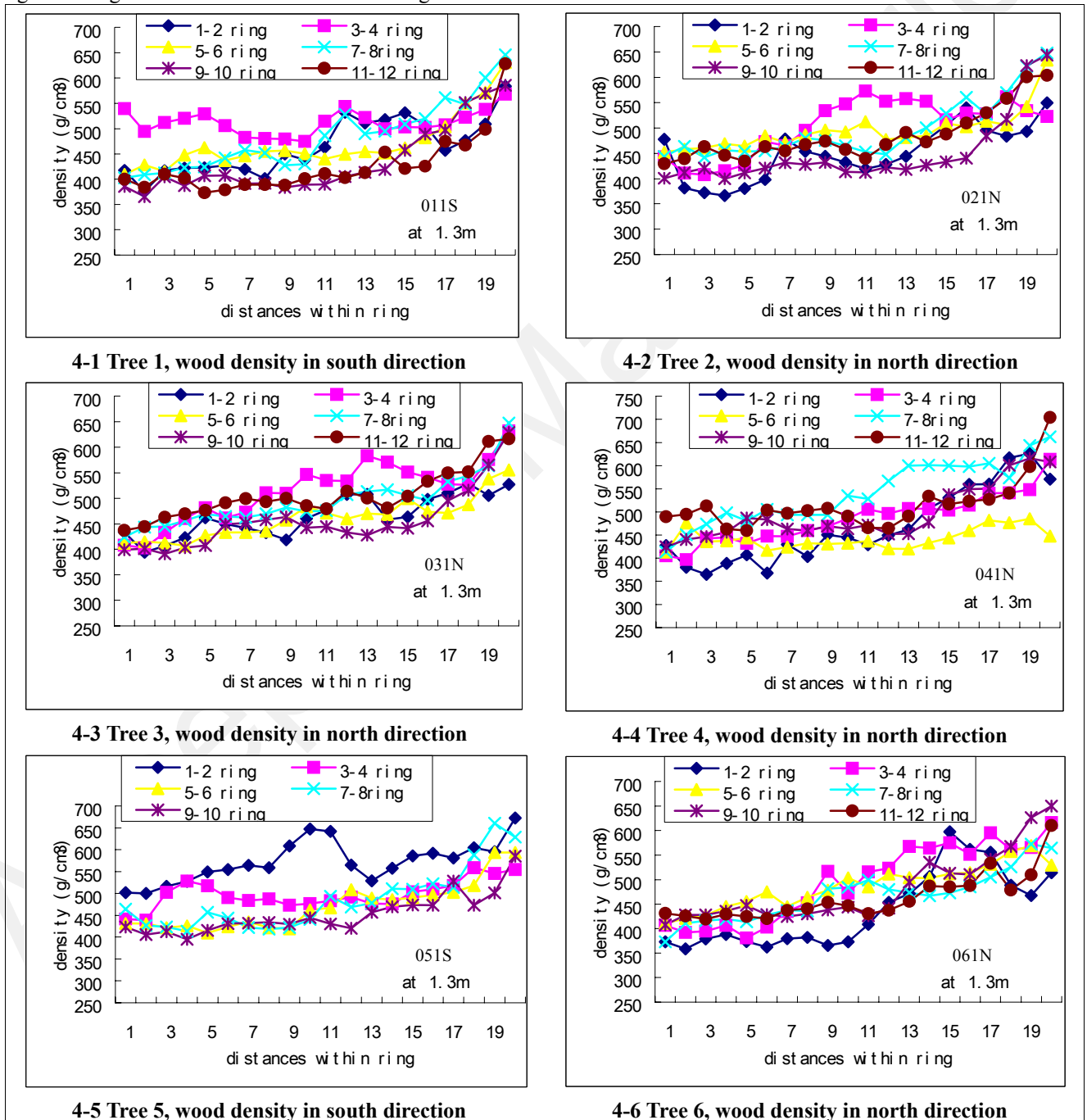


Figure 4. Density variation within the growth rings at 1.3m height of 6 poplar trees (01S, 02N, 03N, 04N, 05S and 06N, N- north direction, S-south direction)

Height effect on axial variations of wood density of poplar I-69

From figure 5, it shows that the general variation pattern of wood density originated from different height is increasing from the bottom (below 2 m) to the upper (above 2 m), and the pattern is similar between earlywood and latewood. The only point should be mentioned here is that the latewood density increases gradually from the bottom to the upper.

When it comes to the axial variation of two kinds of relative density (Figure 6), the pattern is also approximately consistent with former presented densities. In addition, it shows that the DMax-DMin fluctuated heavy at the two extreme heights, e.g.

below 2 m and above 5 m. Nevertheless, the DLW-DEW increases from bottom to 2 m height and levels off upward.

Table 4 shows that the height effect on wood density is significant in tree 1, tree 2 and tree 6, the left is not significant. The earlywood density is only significant in tree 1, tree 2, tree 3 and tree 6, but later wood density is only significant at tree 1 and tree 3. Relative wood density (DMax-DMin and DLW-DEW) is not significant. It indicates that the height effect on wood density including earlywood density and latewood density is significant differently in different trees.

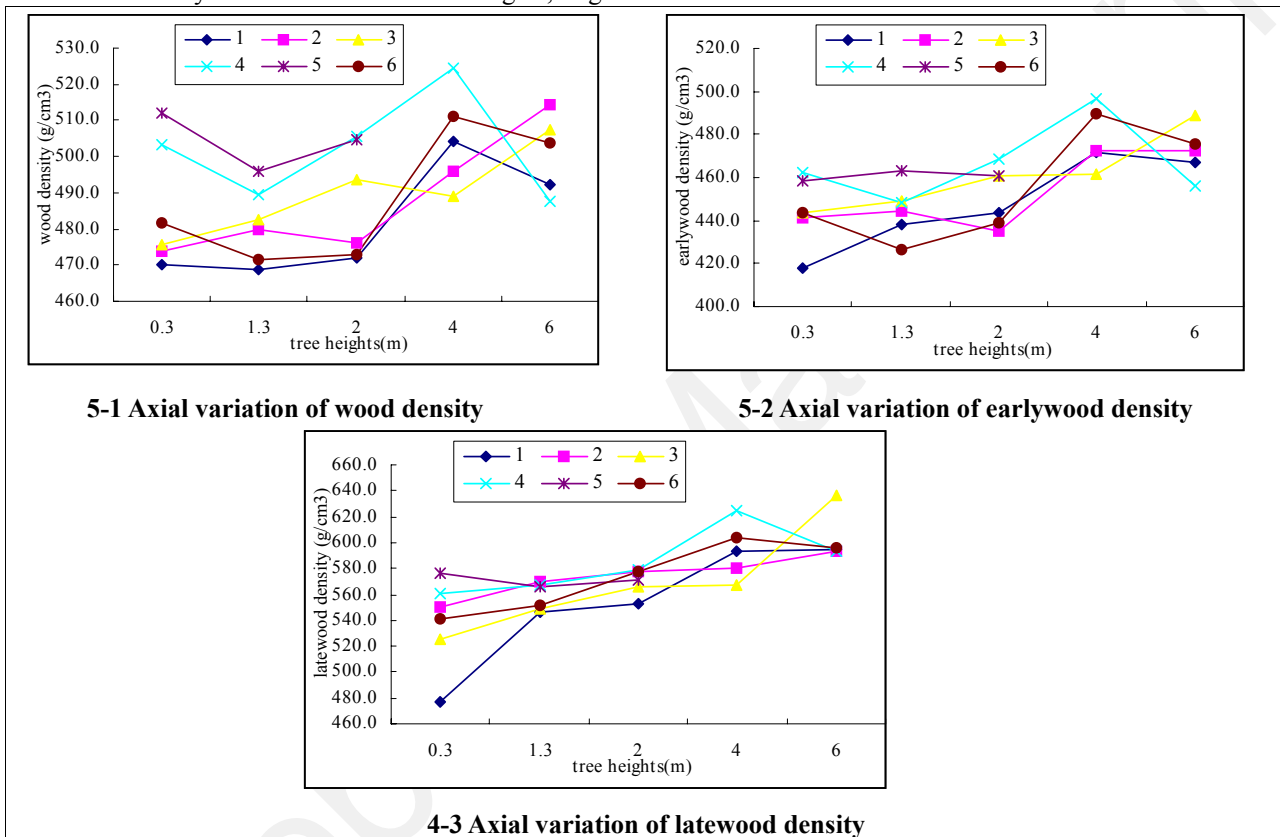


Figure 5. Axial variation of wood density, earlywood density and latewood density of 6 poplar trees (1-tree 1, 2-tree 2, 3-tree 3, 4- tree 4, 5-tree 5, 6- tree 6) at five heights (0.3 m, 1.3 m, 2 m, 4 m and 6 m)

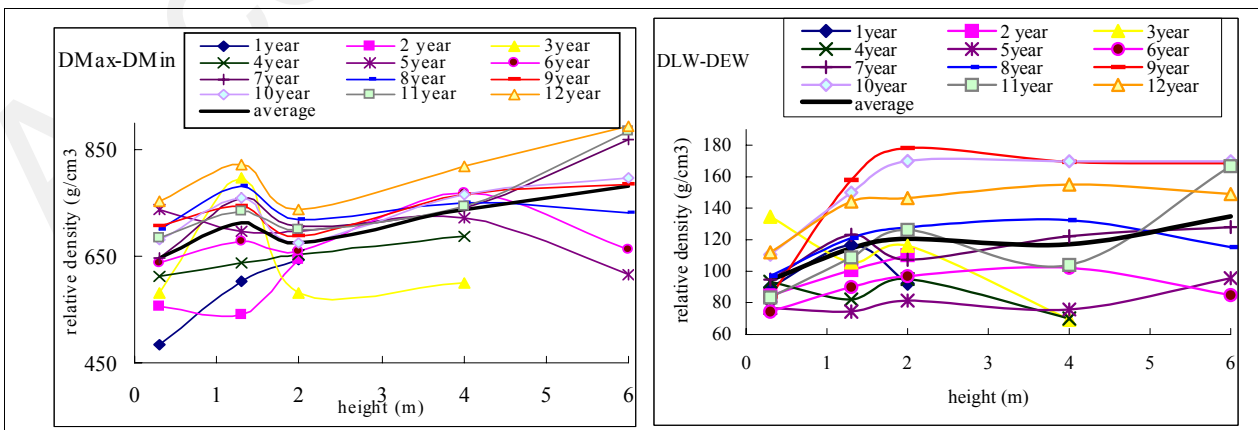


Figure 6. Axial variation of average relative density (DMax-DMin and DLW-DEW) of six trees at different

cambial ages

CONCLUSIONS

1. The effect of silvicultural practice on wood density is significant at the 1% level, but not significant on earlywood density, latewood density and relative wood density.
2. The tree effect on wood density, earlywood density, latewood density and relative wood density is not significant.
3. The cambial age effect on wood density is significant at the 5% level, very significant on earlywood density, latewood density and relative density at the 0.1% level. There are large differences for radial variation patterns of wood density in 6 trees. In general, it has two kinds of radial variation patterns like increasing from pith to bark and decreasing outward at different heights. The wood density within a growth ring increases from earlywood to latewood continuously, but there exists large alteration when the cambial age is less than four years.
4. The height effect on wood density including earlywood density and latewood density is significant differently in different trees. The wood density in the bottom (below 2 m) is lower than the upper one (above 2 m). The DMax-DMin fluctuated heavy below 2m and above 5 m, but the DLW-DEW increases from bottom to 2 m height and levels off upward.

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