TRACHEID LENGTH AND MICROFIBRIL ANGLE OF YOUNG TAIWANIA GROWN UNDER DIFFERENT THINNING AND PRUNING TREATMENTS

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(Received May 2004)

ABSTRACT

The effects of different thinning and pruning methods on the tracheid length and microfibril angle of young Taiwania (*Taiwania cryptomerioides* Hay) were investigated. No significant differences were found for tracheid length and microfibril angle among the three thinning and pruning treatments. The tracheid length increases outwards from the pith. The radial variation in microfibril angle is high near the pith, and declines gradually towards the cambium. The tracheid length values increase with decreasing microfibril angle.

Keywords: Thinning, pruning, tracheid length, microfibril angle, Taiwania.

INTRODUCTION

Tracheid length is recognized as an important wood property. Sirvio and Kärenlampi (2001) indicated that the properties of tracheids depend on maturity and growth rate. The tracheid dimensions usually increase monotonically outwards from the pith, although the longest tracheids are found in the lower middle parts of the bole. Some studies (Saren et al. 2001; Mott et al. 2002; Macdonald and Hubert 2002; Zobel and Sprague 1998) have reported that the tracheid length increases rapidly and nonlinearly during the first years of radial growth, and then more gradually in the mature wood. Thus, tracheid properties appear to vary in a complex way.

Microfibril angle (MFA) is another wood characteristic with a major effect on wood quality, especially shrinkage properties. MFA measurements in wood provide valuable information as an index of mechanical properties and wood quality (Meylan and Probine 1969). For example, the cellulose microfibrils in the S2 layer in wood cells are the most significant contributor

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Wood and Fiber Science, 37(3), 2005, pp. 437–444

to the mechanical properties of wood. Furthermore, the orientation of the microfibrils is critical, with the smallest angle to the cell longitudinal axis often providing the highest mechanical properties. Nakada et al. (2003) and Lichtenegger et al. (1999) also indicated that the microfibril angle of tracheid cell walls is one of the intrinsic and critical characteristics of coniferous wood. It has been found that the microfibril angle decreases from pith to bark (Lichtenegger et al. 1999; Macdonald and Hubert 2002; Zobel and Sprague 1998). Furthermore, there exists a strong correlation between microfibril angle and fiber length, and microfibril angle and fiber strength (Mott et al. 2002; Meylan and Probine 1969). Therefore, these are very important factors in determining the strength and stiffness of wood, apart from consideration of specific end uses.

Koga et al. (1996) indicated that forest product industries depend on intensively managed fast-growing trees because of the depletion of natural timber and the rapidly increasing utilization of wood materials. Also, it is important to stress and promote the role of quality in producing and utilizing wood effectively and economically. Variability in wood traits is mainly affected by genetic, environmental factors and silvicultural practices (Zobel and Sprague 1998; Zobel and van Buijtenen 1989; Lima et al. 2004). In general, tree growth can be directly affected by planting techniques and silviculture, including thinning and pruning, which are the two most important silvicultural practices for commercial plantation wood, controlling tree growth, yield, form, and wood quality. Hence, many studies on the influences of thinning or/and pruning on the wood properties of plantations have been conducted (Zobel and van Buijtenen 1989). However, the influences of thinning and pruning treatments on the anatomic wood properties, such as tracheid length and MFA angle, have received little attention.

Taiwania (*Taiwania cryptomerioides* Hay), is a softwood indigenous to Taiwan. Growth rings are distinct, narrow, and irregular in width frequently with false rings. Transition (dimension of tracheid) from earlywood to latewood is gradual. The wood is straight-grained, fine-textured but without luster. The average fiber length and width are 3.49 mm and 44.5 mm, respectively (Chern 1994). It has become an important species for plantation in Taiwan, because of its fast growth and good wood quality. In a series of investigations on the wood quality of young Taiwania trees grown with different thinning and pruning treatments, it was previously reported that the results included effects on ring width, density, knot traits, bending properties, and strength (Wang et al. 2003a, b). However, there has been little investigation concerning the effects of thinning and pruning practices on the tracheid length and MFA. Therefore, the purpose of this study is to evaluate the effects of silvicultural treatments on the anatomic properties of young Taiwania in plantations.

MATERIAL AND METHODS

Testing materials

The study site was located in the No. 12, Liukuei Experimental Forest of the Taiwan Forestry Research Institute (TFRI), Kaohsiung County, Taiwan, R.O.C. The area of the study site was about 2.0 ha, divided into 27 plots, each about 0.04 ha in area, including a buffer zone. The three types of thinning treatments were heavy thinning (basal area 28 m^2/ha. at diameter breast height [DBH, about 1.3 m. above the ground]), moderate thinning (33 m^2/ha.), and control (42 m^2/ha.). The heavy-thinning and moderate-thinning treatments harvested stocks from the original 42 (m^2/ha) to retain 28 (m^2/ha) and 33 (m^2/ha), respectively. The three types of pruning treatments were heavy pruning (4.5 m), moderate pruning (3.6 m), and control (non-pruning). The heavy-pruning and moderate-pruning treatments represented trees that were pruned from the root base upward to 4.5 m and 3.6 m of the tree height, respectively. The study plantation was planted at an initial density of 2000 trees/ha in 1980. Thinning and pruning treatments were implemented in 1990.

Three levels of thinning were combined with

another three levels of pruning treatment. Therefore, nine silvicultural practices (3 thinning × 3 pruning treatments) were used in this study. The same thinning and pruning treatment plots were repeated three times, for a total of 27 sample plots in the experimental design.

There is large tree-to-tree (inter-tree) and within-tree variation in wood properties within a species; the trees even have the same age and grow in the same condition (Zobel and van Buijtenen 1989; Anagnost et al. 2002; Saren et al. 2001). In this study, the diameter and height of each tree on the 27 small plots were all measured. We had studied the structure of thinning and pruning treatments of Taiwania stands and the expected and fitted Weibull distribution of diameter breast height classes for Taiwania plantations after thinning and pruning treatments (Chiu et al. 2002). To eliminate the variation in this study, trees (samples) were removed only from the mediate tree per plot. In other words, we sampled 3 trees (one [mediate] tree was selected from each plot) of each treatment. The data set consisted of one tree × three replicas (plots) × three thinning treatments × three pruning treatments. In total, 27 trees were investigated for tracheid length and MFA. Each tree had more than nine tracheid lengths and MFAs according to the number of rings examined, respectively.

Experimental method

First, the diameter and height of each tree on the 27 small plots were measured. The average DBHs and tree heights are shown in Table 1. A mean diameter from the trees was selected from each plot (3 trees per treatment), and a total of 27 sample trees were cut. These trees were harvested on February 14–15, 2001, when they were about 20 years old.

One cross-sectional disc (10 cm thick) was cut from each sample tree at the position of its DBH. A pith-to-bark strip about 1 cm wide and 1.5 cm thick was sawn along an average radius from each disk. The diametrical strip was sawn from each disc in the same direction, and each strip was subdivided into growth rings as measuring units. Matchstick-size specimens were trimmed to contain only one growth ring (earlywood and latewood), and then soaked in test tubes with a maceration solution (H_2O_2: CH_3COOH: distilled H_2O = 1: 4: 5). These then were heated at less than 40°C for 72 h until the color of the specimens became transparently white. Then the specimens were removed from the test tubes and washed with distilled water. The bundles of macerated tracheids were stirred and separated with a glass rod, and then stained with Safrain-O.

Tracheid length (TL).—In order to compare tracheid length and microfibril angle (MFA) data on the ring, ring boundary positions for each sample were obtained using Resistograph. The within-ring variances of density and the ring boundaries have been reported in an earlier paper (Wang et al. 2003a). Fortunately, the density profiles for these samples did show clear boundaries. To eliminate within-ring variance in this study, fibers were removed only from the third outermost location of earlywood and all late-

TABLE 1. *Structure of different thinning treatments of Taiwania stands.*

Treatment	Phase	Age (yr)	Density (trees/ha)	Mean DBH (cm)	Mean height (m)	Basal area (m^2/ha)	Volume (m^3/ha)
Heavy thinning	Before thinning	11	1750	17.1	9.85	42.4	197.4
(28 m^2/ha)	After thinning	11	929	19.7	10.41	27.6	131.7
	After 9 years	20	811	28.0	15.21	50.0	342.5
Moderate thinning	Before thinning	11	1689	17.4	9.93	42.2	197.0
(33 m^2/ha)	After thinning	11	1135	19.1	10.32	32.5	154.5
	After 9 years	20	1097	26.6	15.80	60.8	432.1
No thinning	—	11	1801	16.9	9.81	42.0	195.5
(42 m^2/ha)	—	20	1528	23.5	15.50	66.4	463.5

wood (annual ring). Three or four tangential sections, 0.2 mm in thickness, were prepared from each measuring point in the outermost annual ring. After maceration, the tracheids were then washed, dispersed, and mounted on microscope slides.

The number of measurements required was determined through a series of preliminary measurements and using formula $N = t_{\alpha}^2 S^2/E^2$, where t is the student's t value at the α probability level, i.e. $\alpha <= 0.01$ in this study, S^2 is the variation of preliminary sample, and E is the allowable error set at 10% of the mean earlywood/latewood tracheid length (Yang 2002). Based on the results of the preliminary measurement, 60 earlywood and 60 latewood tracheids from a fiber slide were selected and measured, respectively. The 60 tracheids from each earlywood and latewood were measured using a light microscope with a photograph system, respectively. Therefore, there are 120 measurements per each ring (earlywood and latewood) in this study.

In this study, the difference in tracheid length between the earlywood and the latewood shows slight variation, and the mean latewood tracheid length is longer than the mean earlywood. Therefore, the mean length of 60 entire earlywood and 60 entire latewood tracheids was used to represent the tracheid length for each individual ring. In other words, the average length of 120 tracheids was used as the tracheid length for each individual growth ring. Thus, more than 29,160 tracheid lengths were measured (120 replicates × more than 9 rings × 3 trees × 3 thinning treatments × 3 pruning treatments).

Microfibril angle (MFA).—The MFA can be measured by a wide range of techniques, such as the angle of the slit pits, polarizing, fluorescent and electron microscopy, iodine staining, X-ray diffraction (Meylan and Probine 1969; Nakada et al. 2003), soft-rot cavity method (Anagnost et al. 2000), sonication (ultrasonic treatment) (Wang et al. 2001), light microscopy (Senft and Bendtsen 1985), SilviScan (Bonham and Barnett 2001).

In this study, three or four tangential sections, 0.2 mm in thickness, were also prepared from each measuring point in the latewood. After maceration, the tracheids were also then washed, dispersed, and mounted on microscope slides. One MFA (the orientation of the cellulose microfibrils) was measured per tracheid utilizing the common method. The common procedure for measuring MFAs is to dry specimens rapidly. The rapid shrinkage and high drying stresses cause the cell walls to check and split along the direction of the microfibrils in the S2 layer. Subsequent staining enhances the cracks for measurement by light microscopy (observation of images) (Fig. 1). When cell-wall cracks are not present, the angle of elongated pit apertures can be measured, another technique regarded as being closely aligned with the MFA of the S2 cell-wall layer (Senft and Bendtsen 1985). It is agreeable to have a simple, direct, and correct method for MFA determination. Although the method has disadvantages, cracks and pit apertures cannot always be found in sufficient quantity (Senft and Bendtsen 1985).

We regarded the angle of pit apertures against the cell axis on tangential walls of latewood tracheids as the MFA. The angle of the pit aperture is parallel to the MFA of the S2 layer of the cell, and Taiwania usually has a lot of tangential pittings in latewood. One average MFA was measured on individual tracheids. Thereafter, the MFAs were measured in thirty tracheids from

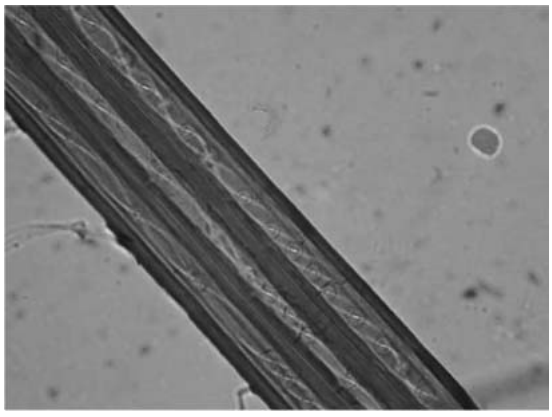

FIG. 1. Measuring microfibril angles of Taiwania under a light microscope.

each latewood using a light microscope with a photograph system.

Thirty measurements were completed for each latewood to obtain a satisfactory estimated means each ring. Therefore, the average angle from each 30 tracheids was taken to be the angle of the ring and was used to represent the MFA in each ring. Each tree had more than 9 MFAs according to the number of rings examined. Thus, more than 7,290 tracheid lengths were measured (30 replicates × more than 9 rings × 3 trees × 3 thinning treatments × 3 pruning treatments).

RESULTS AND DISCUSSION

Effects of thinning and pruning on tracheid length and microfibril angle

The differences in tracheid length and microfibril angle due to different thinning and pruning levels are shown in Table 2. The effects of thinning by pruning interaction on the tracheid length and MFA were not significant (not statistically affected). Therefore, the effects of thinning with a pruning interaction were not analyzed any further.

The average tracheid lengths from the thinning treatments show the following trend: control > moderate-thinning > heavy-thinning. But, no significant differences were found among the thinning treatment specimens. Markstorm et al. (1983) reported that wide differences in radial growth, induced by thinning treatments, were not accompanied by significant differences in specific gravity, latewood percentage, tracheid length, or microfibril angle. Koga et al. (1996) and Zobel and van Buijtenen (1989) reported that latewood tracheid lengths decreased after heavy thinning treatments, but the tracheid lengths were not affected by light thinning treatments. Koga et al. (1997) reported that trees from thinned plots (relatively wide spacing) showed a significant increase in annual ring widths after thinning. Taylor and Burton (1982) indicated that correlations of tracheid length with rate of diameter growth resulted in mostly inverse relationships or in no significant correlation. Little correlation was found for loblolly pine, short-leaf pine, or Virginia pine. However, a negative relationship was reported for slash pine, and a positive relationship has been reported for 8-year-old loblolly pine and mature spruce pine. Koga et al. (1996) noted that there are some reports of negative relationships between growth rates and tracheid length. It was explained that this was due mainly to the frequency of pseudotransverse divisions of the cambial initials. Therefore, in this study, these results agree with reports that tracheid length declines after thinning, as explained by an increase in the frequency of pseudotransverse division of the cambial initial, accompanied by accelerated growth rate.

TABLE 2. *Fiber length and microfibril angle obtained from different thinning and pruning regimes.*

Treatment	Heavy	Moderate	No treatment
Fiber length (mm)			
Thinning	3.10 (0.20)	3.11 (0.27)	3.17 (0.11)
Pruning	3.15 (0.18)	3.12 (0.17)	3.22 (0.26)
Microfibril angle			
Thinning	18.7 (1.3)	18.8 (1.8)	16.9 (1.1)
Pruning	18.3 (2.0)	17.9 (1.5)	18.2 (1.4)

The average tracheid lengths from the pruning treatments showed the following trend: nonpruning > heavy-pruning > moderate-pruning. But, no significant differences were found. Wang et al. (2003a) reported that trees from pruned plots showed a trend for annual ring widths to decrease after pruning. The principal effects of pruning treatments or removal of live branches (crowns) are to depress tree growth and to reduce the influence of the photosynthesis effect. Therefore, tracheid length declines after pruning, perhaps due to a decrease in the frequency of growth division. DeBell et al. (2002) indicated that mean ring width, wood density, and fiber length at either stem height of many clones were not affected significantly by pruning. This was because pruning effects on current wood anatomy might last only as long as treatment-related differences in crown length were maintained, and subsequently would diminish or disappear.

In addition, the average microfibril angle from the thinning treatments showed the following trend: moderate-thinning >/≒ heavy-thinning > control. But, no significant differences were found. Markstorm et al. (1983) reported that wide differences in radial growth, induced by thinning treatments, were not accompanied by significant differences in microfibril angle. The above-mentioned results (changes of tracheid length and microfibril angle) were fluctuation in thinned and pruned trees, but the differences were not significant.

Variation in mean tracheid length and microfibril angle at breast heights

Variations in mean tracheid length and microfibril angle at breast height are given in Figs. 2 and 3. As shown in Fig. 2, the tracheid length increased rapidly up to the 9th and 10th year rings, and then remained about constant from the 10th to 19th year rings. Saren et al. (2001) reported that the tracheid length increased rapidly up to the 5th to 10th year rings, was quite constant from the 10th to 30th year rings, and then increased again slightly after that. Sirvio and Kärenlampi (2001) indicated that the tracheid dimensions usually increase monotonically outwards from the pith, but the longest tracheids are found from the lower middle parts of the bole. Other studies have reported that a characteristic pattern of increasing tracheid length outward from the pith at any one level is generally recognized (Saren et al. 2001; Mott et al. 2002; Macdonald and Hubert 2002).

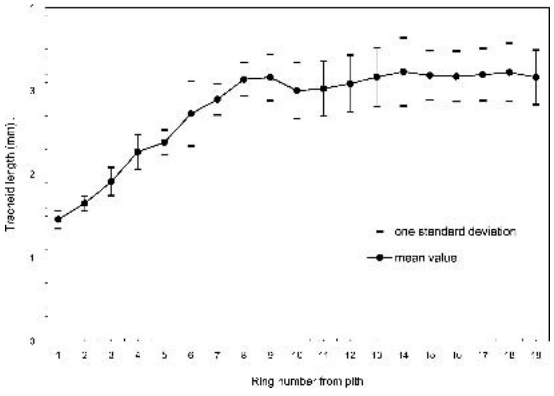

FIG. 2. Variation in mean tracheid length at breast height.

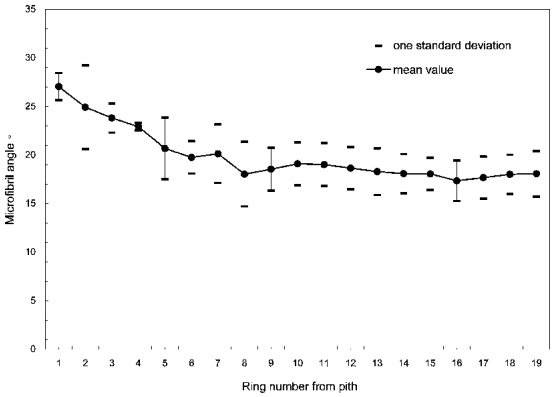

FIG. 3. Variation in mean microfibril angle at breast height.

As shown in Fig. 3, the microfibril angle decreased rapidly up to the 8th and 10th year rings, and then was almost constant from the 10th to 19th year rings. Saren et al. (2001) reported that the microfibril angle decreased rapidly from the pith toward the bark and became quite constant by year rings 5–10 (about 8°). Lima et al. (2004) indicated that the MFA seemed to decrease slightly from pith to bark in a nonlinear fashion. Many researchers indicated that the accepted pattern of radial variation in microfibril angle in conifers is from a high value in the rings near the pith, declining gradually towards the cambium (Lichtenegger et al. 1999; Macdonald and Hubert 2002; Nakada et al. 2003; Zobel and Sprague 1998). Therefore, the results of variation in mean tracheid length and microfibril angle in this study correspond to these reports.

Correlations between the microfibril angle and the tracheid length

Relationships between the microfibril angle and the tracheid length are shown in Fig. 4. It is clear that the tracheid length values decreased with increasing MFA, and the relation could be expressed by the second-order polynomial regression (in Fig. 4). The determination coefficients (R^2) were highly significant at the 0.01

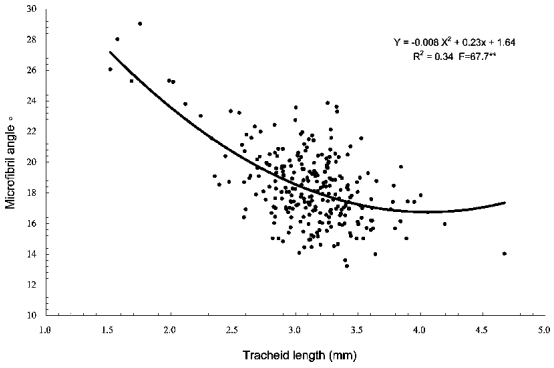

FIG. 4. Relationships between the microfibril angle and the tracheid length.

level, as indicated by the F value test. Mott et al. (2002) indicated that there exists a strong correlation between microfibril angle and fiber length, as well as between microfibril angle and fiber strength. Earlywood fibers are generally shorter than latewood fibers of the same growth increment but exhibit a higher microfibil angle. Bonham and Barnett (2001) indicated that the pith-to-bark trends of microfibril angle decrease and fiber length increases, indicating a correlation between the two fiber properties. The relationship of microfibril angle to tracheid length found in softwoods has been explained as a result of the manner in which microfibrils are formed, which is influenced by the size of the tracheid at the time of deposition. Thus, the results in this study are in agreement with these previous studies.

CONCLUSIONS

The effects of different thinning and pruning methods on the tracheid length and microfibril angle of immature Taiwania were investigated, with the following results:

1. No significant differences were shown for tracheid length and microfibril angle among the three thinning and pruning treatments specimens. The average tracheid length from the thinning treatments showed the following trend: control > moderate-thinning > heavy-thinning. The average tracheid length from the pruning treatments showed the following trend: non-pruning > heavy-pruning > moderate-pruning. In addition, the average microfibril angle from the thinning treatments showed the following trend: thinning > control.
2. The tracheid length increased rapidly up to the 9th and 10th year rings, and then was about constant from the 10th to 19th year rings.
3. The microfibril angle decreased rapidly up to the 8th and 10th year rings, and then was almost constant from the 10th to 19th year rings.
4. The tracheid length values increased with decreasing microfibril angle, and this relation could be expressed by a second-order polynomial regression.

ACKNOWLEDGMENTS

The authors thank the Taiwan Forestry Research Institute (TFRI) and the National Science Council of ROC for financial support (NSC92-2313-B-002-119). This paper is a contribution of the TFRI (No. 311).

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