Growth and Wood Quality of Sugi and Hinoki Trees in the Plantations of the Wakayama Experiment Forest

By
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Abstract

The present study was carried out to investigate the growth and wood quality of sugi (Cryptomeria japonica) and hinoki (Chamaecyparis obtusa) planted in the Wakayama Experiment Forest. Prior to the examination of the trees, the soils were surveyed in the plantations and a natural secondary broad-leaved forest. Trees over 50 years old were stem-analyzed, and the wood was examined for moisture content, basic density, annual ring width and the proportion of heartwood. The results showed that the soils were sufficiently wet or slightly dry brown forest ones (B_D or B_C type in the Japanese forest soil classification method) and rich in gravel. The growth and wood quality of both kinds of trees were excellent, even compared with those produced in the famous forestry districts. Though the hinoki was a little inferior to the sugi in its growth, it was superior to the sugi in its wood quality, for instance in its uniformity of annual ring width. The heartwood of the sugi trees was remarkably dark brown in color and had a high moisture content, as is often seen in sugi of other districts, and the wood of the sugi trees is considered a kind of wetwood.

Key words; Forest soil, Sugi (Cryptomeria japonica), Hinoki (Chamaecyparis obtusa), Stem analysis, Wood quality.

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Introduction

Afforestation has been actively practiced in Japan since the end of World War II. At present about 40% of the total forest area (25 million ha) is occupied by artificial forests, in which sugi (Cryptomeria japonica D.Don) and hinoki (Chamaecyparis obtusa ENDL.) have been mainly planted throughout the country excluding the greater part of Hokkaido. Sugi, which has a number of regional varieties, is the only species in the genus Cryptomeria and is well suited to wet brown forest soils and the warm and humid conditions occurring in the growing season peculiar to Japan, while hinoki is well suited to properly wet or slightly dry brown forest soils. Consequently, it is generally planted at higher elevations than sugi. Recently they are being planted at an annual rate of over 30,000 ha each1). Both kinds of wood are widely used for structural timber and furnishings in Japanese houses.

In the Wakayama Experiment Forest, Hokkaido University, the two species have also been widely planted since its foundation. However, studies on the growth and wood quality of the trees as well as on the forest soils in the Experiment Forest have been almost nonexistent. Thus, we investigated the forest soils of the plantations and a natural forest in March, 1982, and studied the sugi and hinoki which were over 50 years old in 1988 by examining their process of growth through the stem analysis method and their physical properties of moisture content, basic density, annual ring width and the proportion of heartwood.

A number of studies on sugi and hinoki have been reported; with regard to the physical properties listed above, Yazawa26,27), Miyoshi12), Hirai23–25), Sakata and Saeki14), Yazawa and Fukazawa28,29), and Fukazawa2) have described them in detail. Meanwhile, there also have been many general research books published on sugi and hinoki13–16,17–20).

We are deeply indebted to and would like to express our gratitude towards the members of the Wakayama Experiment Forest and Mr. I.Tanaka, former instructor, for their kind assistance in the surveys and examinations.

Outline of the Wakayama Experiment Forest10)

The Wakayama Experiment Forest was founded in 1925 with the purchase of about 430-ha forest from private owners. It was purchased to allow the study of warm temperate forests and to provide a place for student training in the University. As shown
Fig. 1. Location of experimental sites in the Wakayama Experiment Forest.
Note: The figures are the compartment Nos.

in Fig. 1, it is situated at 135°40' east longitude and 33°40' north latitude, belonging administratively to Kozagawa Town, Wakayama Prefecture. In terms of geology, the area exists on Paleogenic strata classified into the Mu ro group composed of sandstone, mudstone and their alternated beds. The topographical features show the land is generally steeply sloped. The forest is located in the area around the uppermost stream of the Hirai River, a tributary of the Koza River. Concerning the climate, as shown in Table 1, the annual mean temperature is 15.4°C and yearly precipitation is 3,760 mm, over 70 % of

| Table 1. Climatological data of the Wakayama Experiment Forest |
|-------------------|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean temperature (°C) | 5.3  | 6.3  | 14.6 | 17.5 | 21.8 | 25.0 | 25.5 | 22.9 | 17.7 | 12.6 | 7.5  | 15.4 |
| Mean max. temperature (°C) | 11.6 | 12.1 | 15.1 | 20.0 | 23.5 | 26.3 | 29.8 | 30.1 | 27.8 | 23.6 | 18.1 | 13.8 | —   |
| Mean min. temperature (°C) | -1.1 | 0.6  | 2.9  | 8.7  | 12.5 | 17.4 | 20.9 | 21.4 | 18.4 | 12.7 | 7.0  | 1.6  | —   |
| Precipitation (mm)     | 123.3 | 193.7 | 254.7 | 422.5 | 476.8 | 497.8 | 411.0 | 408.5 | 243.4 | 184.9 | 121.1 | 313.4 |
| Evaporation (mm)       | 59.9  | 66.2  | 89.6  | 96.2  | 112.5 | 93.3  | 116.8 | 112.3 | 90.7  | 80.6  | 64.8  | 54.8  | 86.5 |
| Time of sunshine (hr)  | 151.0 | 154.5 | 156.5 | 144.8 | 163.8 | 106.2 | 142.4 | 140.4 | 121.2 | 150.4 | 122.7 | 147.4 | 141.8 |

** The figures in parenthesis are the yearly precipitation and sunshine hours.
Observed period: 10 years from 1971 to 1980.
which falls from April to September. Compared to other seasons, winters are dry with many hours of sunshine, though sometimes snowfalls of several centimeters deep occur.

Since it belongs phytogeographically to the northern warm temperate zone, the natural forest is a mixed ever-green broad-leaved forest (called Shoyo-jurin) consisting mainly of *Stilia* and *Quercus* species, with some deciduous trees and conifers such as *Abies firma* and *Tsuga sieboldi* in the higher altitudes. However, as the climatic conditions are well suited to sugi and hinoki, they have been planted since 1928 under the management plan for the conversion of secondary forests in the Experiment Forest. At present, artificial forests account for 75% of the total area. And research based on the new management plan is being actively pursued, including experiments on the conversion to an artificial multi-storied forest and the production of high-value wood like knot-free-faced boxed heart timber for Japanese houses\(^1\). In the rest of the Experiment Forest there are various experimental arboretums and forest reserves including a 59-ha broad-leaved old growth forest.

**Experiment Sites**

As shown in Fig. 1 and Table 2, three experimental plots were selected: Plot 1 in the

<table>
<thead>
<tr>
<th>Plot Site (Compartment)</th>
<th>Forest</th>
<th>Year of plantation</th>
<th>Elevation (m)</th>
<th>Slope and planting direction</th>
<th>Planting number (seedlings/ha)</th>
<th>Living number (Stems/ha)</th>
<th>Average Height (m)</th>
<th>Average D.B.H. (cm)</th>
<th>Growing stock (Stems/ha)</th>
<th>Average S.D. of stock (Stems/ha)</th>
<th>Grooving stock (Stems/ha)</th>
<th>Average S.D. of stock (Stems/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 *1</td>
<td>Sugi artificial forest</td>
<td>1936</td>
<td>520</td>
<td>20'S</td>
<td>4,650</td>
<td>1,000</td>
<td>22.6</td>
<td>2.59</td>
<td>28.5</td>
<td>6.35</td>
<td>685</td>
<td>19-27</td>
</tr>
<tr>
<td>2 *1</td>
<td>Hinoki artificial forest</td>
<td>1936</td>
<td>560</td>
<td>19'S</td>
<td>4,650</td>
<td>1,200</td>
<td>21.7</td>
<td>1.44</td>
<td>26.5</td>
<td>4.52</td>
<td>748</td>
<td>19-24</td>
</tr>
<tr>
<td>3 16</td>
<td>Natural secondary broad-leaved forest</td>
<td>-</td>
<td>320</td>
<td>38'SE</td>
<td>2,400</td>
<td>11.7</td>
<td>6.28</td>
<td>12.8</td>
<td>7.16</td>
<td>404</td>
<td>6-28</td>
<td>6-30</td>
</tr>
</tbody>
</table>

Note: Surveyed in May, 1988.
\(*1\): Two-storied forests, now made by underplanting of sugi seedlings in 1983 and 1984.
\(*2\): S.D.; Standard deviation.
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two-storied forests) by the underplanting of sugi seedlings after the selection cutting of about 30% in 1982 to 1983.

Each forest was surveyed as to the number of trees, their height and diameter at breast height (D.B.H.) in a 10 × 10 m² area in May, 1988. At Plot 1, the living trees numbered 1,000 per hectare, with the average height being 22.6 m ranging from 19 to 27 m, and the average D.B.H. being 28.5 cm ranging from 18 to 37 cm. The growing stock was calculated at 685 m³ per hectare. At Plot 2, the living trees numbered 1,200 per hectare, with the average height being 21.7 m ranging from 19 to 24 m, and the average D.B.H. being 26.5 cm ranging from 16 to 32 cm. The growing stock was calculated at 748 m³ per hectare. At Plot 3 located at a mean elevation of 320 m and facing southeast at a slope angle of 38°, the trees numbered 2,400 per hectare, consisting of 18 kinds of trees, including such species as Quercus glauca, Q. paucidentata, Q. stenophylla, Shiia cuspidata, Litsea aciculata, Ilex sugeroki var. longipedunculata, Actinodaphne acuminata, Cleyera ochracea, and Sapindus mukuo. The average height was 11.7 m ranging from 6 to 28 m, while the average D.B.H. was 12.8 cm ranging from 6 to 30 cm. The growing stock was calculated at 404 m³ per hectare.

Methods

1. Survey of soils

The soils were surveyed at Plots 1, 2 and 3 in March, 1982. A pit was made in the center of each Plot by digging to a 70 to 90-cm depth, the exact depth depending on the appearance of the fine roots of the trees. The soils profile observed was divided by the naked eye into A, B and B' horizons, and their thickness was measured. According to the standard procedure for analyzing soil properties in the field[22,23], color, hardness, structure, and soil class were examined. The soils of each horizon were collected under natural conditions with 100-ml cylindrical core samplers and were tested for apparent specific gravity, moisture content and three-phase distribution in the laboratory. Gravel content in the soils was also determined.

2. Stem analysis

As shown in Table 3, three trees (two sugi and one hinoki) were felled at a 30-em height from Plots 1 and 2, and stem-analyzed by Nakajima's method[22,23]. One of the sugi trees from Plot 1 was 53 years old and had a nearly average size (sugi 1), while the other was 54 years old and 4 m taller than the average (sugi 2). The hinoki tree from Plot 2 was 53 years old and also somewhat taller than the average. From Plot 3 an arakashi (Quercus glauca) tree was felled, having a D.B.H. of 9.5 cm and a height of 11.9 m. The annual ring

<table>
<thead>
<tr>
<th>Tree</th>
<th>Site (Compartment)</th>
<th>Height (m)</th>
<th>D.B.H. (cm)</th>
<th>Age (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugi 1</td>
<td>5</td>
<td>23.6</td>
<td>28.4</td>
<td>53</td>
</tr>
<tr>
<td>Sugi 2</td>
<td>5</td>
<td>26.8</td>
<td>28.5</td>
<td>54</td>
</tr>
<tr>
<td>Hinoki</td>
<td>5</td>
<td>23.8</td>
<td>25.7</td>
<td>53</td>
</tr>
<tr>
<td>Arakashi</td>
<td>16</td>
<td>11.9</td>
<td>9.5</td>
<td>50*&lt;</td>
</tr>
</tbody>
</table>

* Annual ring number of the wood disc at 1.3-m height.
of the tree numbered 50 at a 1.3-m height, and their width was as narrow as 1 mm, so that stem analysis was difficult and given up. From the analysis of the sugi and hinoki trees, their general growth and their annual as well as periodic increments of height, D.B.H., sectional area and volume were calculated.

3. Examination of wood quality

Each wood disc used for stem analysis was measured for the diameter of its heartwood, and then cut into a rectangular piece of a 2-cm width including the pith, and also into the same piece at the right angle as it. These pieces were cut into blocks having a thickness of 5 annual rings from the pith. The examinations for wood quality were carried out with the blocks on moisture content, basic density, annual ring width and the proportion of heartwood. The volume figures for the basic density measured were determined using a mm-unit rule. The values were averaged over the four directions, neglecting the values obtained from knotty blocks. For the arakashi tree, only the wood disk cut at a 1.3-m height was used for the examination of these physical properties.

Results

1. Soil properties

The properties of the soils under natural condition are shown in Table 4. All the soils observed had A₀ layer, A and B horizons, and were brown forest soils being slightly dry (B_C type) at Plot 1 and 3, and sufficiently wet (B_D type) at Plot 2 which is, though, located in a higher elevation. The thickness of the A₀ layer ranges from 2.5 cm at the sugi plantation (Plot 1) to 8.0 cm at the natural broad-leaved forest (Plot 3), with being composed mainly of the F layer. The reason why the A₀ layer of Plot 3 is so thick might be because the forest is dark due to the high density of ever green trees. The A horizon of Plots 1 and 3 is as thick as 40 cm, and rich in humus, showing a color of 7.5 YR2/3 or 10YR3/3 with Munsell's notation and a loose or soft consistency, while that of Plot 2 is 19 cm thick and not so rich in humus judging from its color. The brown colored B horizon is over 45 cm thick, scarce in the humus and slightly hard showing 15 to 17 mm on the hardness tester. Furthermore, the soils all have a loamy texture (L, SiL and SL by soil class), crumb structure and fairly high gravel content, which permit proper water permeability and

<table>
<thead>
<tr>
<th>Plot</th>
<th>Site</th>
<th>Forest</th>
<th>Soil type</th>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Thickness (cm)</th>
<th>Color</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>Sugi</td>
<td>B_C</td>
<td>A₀</td>
<td>2.5</td>
<td>10YR2/3</td>
<td>brownish black</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>planted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>by naked eye</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in 1936</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10YR4/4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>0-40</td>
<td>40</td>
<td>7.5YR2/3</td>
<td>very dark brown</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>40-85</td>
<td>45&lt;</td>
<td>10YR5/6</td>
<td>yellowish brown</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Hinoki</td>
<td>B₀</td>
<td>A₀</td>
<td>4.0</td>
<td>10YR3/3</td>
<td>dark brown</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>planted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>by naked eye</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in 1936</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10YR5/6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>0-19</td>
<td>19</td>
<td>10YR3/4</td>
<td>dark brown</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>19-70</td>
<td>51&lt;</td>
<td>10YR5/6</td>
<td>yellowish brown</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>Natural</td>
<td>B_C</td>
<td>A₀</td>
<td>8.0</td>
<td>7.5YR2/3</td>
<td>very dark brown</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>by naked eye</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>broad-leaved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10YR5/6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>0-40</td>
<td>40</td>
<td>10YR3/3</td>
<td>dark brown</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>40-90</td>
<td>50&lt;</td>
<td>10YR5/4</td>
<td>dull yellowish brown</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 4. Properties of soils
aeration. The gravels consist of breccia of some 5 cm in size, and are contained even in the A₀ layer at Plots 1 and 3, which can probably be attributed to settling from the top. Thus, under such soil conditions the trees could have sufficient growth.

From the analysis with the core sampler it was found that the apparent specific gravity of the soils is high and that their moisture content is moderate. However, the moisture content in the A₀ layer is as high as 284.1% of dry matter at Plot 2. The three-phase distribution shows that the rate of solid is very high, especially in the B horizon, as compared with general forest soils.

2. Tree growth

Illustrations from the stem analyses of sugi 1, sugi 2, and the hinoki are presented in Figs. 2, 3, and 4, respectively. Since the diameter growth is usually calculated using the value from each disk, the disk surface is treated as true circle. The circle index of the different disks obtained from the proportion of the longer diameter to the shorter one is also given on the right side of each Figure. The growth in height and volume of sugi 1, and 2, and the hinoki are shown in Tables 5, 6, and 7, respectively.

The trees selected have generally grown well, especially as seen in the process of

<table>
<thead>
<tr>
<th>Structure</th>
<th>Soil class</th>
<th>Humus content</th>
<th>Gravel content (%)</th>
<th>Apparent specific gravity (fresh soil)</th>
<th>Moisture content based on (%)</th>
<th>Distribution of three-phase (vol. %)</th>
<th>Porosity (vol. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- - - very rich</td>
<td>21</td>
<td>0.57</td>
<td>0.30</td>
<td>48.2</td>
<td>93.0</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>crumb SIL rich</td>
<td>15</td>
<td>0.99</td>
<td>0.59</td>
<td>40.5</td>
<td>68.2</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>crumb L containing</td>
<td>10</td>
<td>1.46</td>
<td>1.00</td>
<td>32.1</td>
<td>47.4</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>- - - very rich</td>
<td>0</td>
<td>0.45</td>
<td>0.12</td>
<td>74.0</td>
<td>284.1</td>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>crumb L containing</td>
<td>32</td>
<td>1.15</td>
<td>0.66</td>
<td>43.3</td>
<td>76.3</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td>crumb L scarce</td>
<td>32</td>
<td>1.37</td>
<td>0.89</td>
<td>35.7</td>
<td>55.4</td>
<td>33</td>
<td>49</td>
</tr>
<tr>
<td>- - - very rich</td>
<td>15</td>
<td>0.43</td>
<td>0.14</td>
<td>67.1</td>
<td>203.9</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>crumb SIL rich</td>
<td>32</td>
<td>1.12</td>
<td>0.76</td>
<td>32.1</td>
<td>47.3</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>crumb SIL scarce</td>
<td>23</td>
<td>1.50</td>
<td>1.16</td>
<td>22.9</td>
<td>29.7</td>
<td>43</td>
<td>34</td>
</tr>
</tbody>
</table>

Fig. 2. Stem analysis of sugi 1.

* The proportion of the longer diameter to the shorter one on the tree-disk at different heights.
growth in sugi 2 in its young stage. Concerning their growth in height, Tables 5, 6, and 7 show that sugi 2 attained a height of 7.3 m when 10 years old, while sugi 1 and the hinoki attained heights of only 3.3 and 3.8 m, respectively. However, the recent growth in height of both sugi was decreasing to a growth rate below 1%, while that of the hinoki was about 1.6%. The final height of each tree was 23.6, 26.8, and 23.8 m, the final volume was 0.7126, 0.7856, and 0.6265 m³ including the bark, and the mean increment was 0.0123, 0.0136, and 0.0109 m³ per year for sugi 1, 2, and the hinoki, respectively. The most recent volume growth rate of the bigger sugi (sugi 2) was only 2%, while the rate of the others was
**Table 5. Height and volume growths of sugi 1**

<table>
<thead>
<tr>
<th>Age class</th>
<th>Height (m)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth</td>
<td>Periodic increment</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>10</td>
<td>3.3</td>
<td>2.3</td>
</tr>
<tr>
<td>15</td>
<td>9.3</td>
<td>6.0</td>
</tr>
<tr>
<td>20</td>
<td>11.8</td>
<td>2.5</td>
</tr>
<tr>
<td>25</td>
<td>14.5</td>
<td>2.7</td>
</tr>
<tr>
<td>30</td>
<td>16.5</td>
<td>2.0</td>
</tr>
<tr>
<td>35</td>
<td>18.3</td>
<td>1.8</td>
</tr>
<tr>
<td>40</td>
<td>20.0</td>
<td>1.7</td>
</tr>
<tr>
<td>45</td>
<td>21.7</td>
<td>1.7</td>
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<tr>
<td>50</td>
<td>23.0</td>
<td>1.3</td>
</tr>
<tr>
<td>53</td>
<td>23.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

* The figure in parenthesis is the volume including bark.

**Table 6. Height and volume growths of sugi 2**

<table>
<thead>
<tr>
<th>Age class</th>
<th>Height (m)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth</td>
<td>Periodic increment</td>
</tr>
<tr>
<td>5</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>10</td>
<td>7.3</td>
<td>4.0</td>
</tr>
<tr>
<td>15</td>
<td>11.3</td>
<td>4.0</td>
</tr>
<tr>
<td>20</td>
<td>14.6</td>
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<td>18.9</td>
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<td>20.9</td>
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<td>24.3</td>
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<td>25.8</td>
<td>1.5</td>
</tr>
<tr>
<td>54</td>
<td>26.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* The figure in parenthesis is the volume including bark.

over 4%.

The circle index shows that the cross section of the hinoki stem is as round as 1.05 on the average, but the cross sections of the sugi stems are more elliptical, with values at 1.13 and 1.16.

3. Physical properties of the wood

The distributions of moisture content, basic density, annual ring width, and the
Table 7. Height and volume growths of the hinoki

<table>
<thead>
<tr>
<th>Age class</th>
<th>Height (m)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth</td>
<td>Periodic</td>
</tr>
<tr>
<td></td>
<td>increment</td>
<td>increment</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>1.3</td>
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<td>10</td>
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<td>9.8</td>
<td>3.3</td>
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<td>12.1</td>
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<td>30</td>
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<td>16.1</td>
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<td>50</td>
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<td>53</td>
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<tr>
<td>(53)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The figure in parenthesis is the volume including bark.

Table 8. Distribution of moisture content in the wood of sugi 1

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average of heartwood</th>
<th>Average of sap-wood</th>
<th>Average of wood</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>150 165 199 192 200 133 106 149 175 174 234</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>167 186 185 192 183 97 162 219 205 234</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>132 122 136 100 84 182 196 174 200</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>127 73 82 82 93 144 187 170 204</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3</td>
<td>136 75 72 71 90 160 174 160 193</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.3</td>
<td>167 181 124 81 156 158 144 180</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.3</td>
<td>165 174 130 71 115 165 146 180</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.3</td>
<td>172 159 92 120 156 136 179</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.3</td>
<td>167 148 95 127 149 184</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.3</td>
<td>167 109 140 156 180</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.3</td>
<td>145 118 143 167</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.3</td>
<td>141 129 161</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.3</td>
<td>171 171</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23.3</td>
<td>170</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand average</td>
<td>132 170 159 120</td>
<td>163 183 175 113</td>
<td>168 205 190 123</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Weighted average calculated with the proportion of heartwood area (cf. Table 11).

The proportion of heartwood in the wood of sugi 1 are presented in Tables 8, 9, 10, and 11, respectively. As shown in Table 8, the moisture content is as high as 159% on the average, including that of the heartwood. The range extends from 71 to 234%. Though the
### Table 9. Distribution of basic density in the wood of sugi 1 (kg/m²)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>448 382 366 371 356 377 363 315 331 358 314</td>
<td>362</td>
<td>423</td>
</tr>
<tr>
<td>1.3</td>
<td>428 409 405 388 402 395 334 338 365 365 483</td>
<td>380</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>335 372 402 396 391 363 325 412 365 373 382</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>350 357 422 445 437 427 383 446 442 412 426</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3</td>
<td>395 408 389 403 421 379 363 426 399 385 404</td>
<td>398</td>
<td>404</td>
</tr>
<tr>
<td>9.3</td>
<td>465 396 441 470 394 382 444 406 425 389 404</td>
<td>425</td>
<td>389</td>
</tr>
<tr>
<td>11.3</td>
<td>443 442 432 464 427 396 442 429 434 373 439</td>
<td>439</td>
<td>390</td>
</tr>
<tr>
<td>13.3</td>
<td>443 446 457 433 406 480 411 439 404 390 404</td>
<td>465</td>
<td>442</td>
</tr>
<tr>
<td>15.3</td>
<td>467 477 488 427 481 448 465 442 439 404 404</td>
<td>444</td>
<td>432</td>
</tr>
<tr>
<td>17.3</td>
<td>457 427 416 490 432 444 432 421 414 379 414</td>
<td>452</td>
<td>421</td>
</tr>
<tr>
<td>19.3</td>
<td>464 427 453 465 452 434 421 395 322 300 400</td>
<td>414</td>
<td>379</td>
</tr>
<tr>
<td>21.3</td>
<td>393 388 462 388 322 388 388 300 322 300 400</td>
<td>395</td>
<td>322</td>
</tr>
<tr>
<td>23.3</td>
<td>400 400 400 388 322 388 388 300 322 300 400</td>
<td>400</td>
<td>320</td>
</tr>
<tr>
<td>Grand average</td>
<td>409 392</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.-Max.</td>
<td>314-490</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 10. Distribution of annual ring width in the wood of sugi 1 (mm)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>4.0 5.5 3.3 3.1 2.4 2.2 2.3 2.7 3.4 3.5 2.6</td>
<td>3.2</td>
</tr>
<tr>
<td>1.3</td>
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<td>2.9</td>
</tr>
<tr>
<td>3.3</td>
<td>5.1 3.4 2.7 2.4 2.2 2.1 3.0 1.9 2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>5.3</td>
<td>5.7 3.6 2.5 2.3 1.8 2.1 2.7 2.0 1.8</td>
<td>2.7</td>
</tr>
<tr>
<td>7.3</td>
<td>5.0 4.5 3.1 2.3 1.8 2.1 2.6 1.8 1.5</td>
<td>2.7</td>
</tr>
<tr>
<td>9.3</td>
<td>4.8 4.0 2.9 1.9 2.0 2.4 1.8 2.1</td>
<td>2.7</td>
</tr>
<tr>
<td>11.3</td>
<td>3.7 4.7 3.3 2.0 2.1 2.7 1.7 2.3</td>
<td>2.8</td>
</tr>
<tr>
<td>13.3</td>
<td>3.6 4.0 2.9 2.6 2.8 1.9 1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>15.3</td>
<td>3.2 3.4 3.1 3.3 2.2 2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>17.3</td>
<td>2.3 4.0 3.6 2.4 1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>19.3</td>
<td>3.0 3.4 2.5 2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>21.3</td>
<td>3.0 2.5 3.1</td>
<td>2.9</td>
</tr>
<tr>
<td>22.3</td>
<td>2.3 3.4</td>
<td>2.9</td>
</tr>
<tr>
<td>23.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>2.84</td>
</tr>
<tr>
<td>Min.-Max.</td>
<td></td>
<td>1.5-5.7</td>
</tr>
</tbody>
</table>
Table 11. Distribution of heartwood proportion in the wood of sugi 1

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Annual ring number of heartwood</th>
<th>Proportion of diameter* (%)</th>
<th>Proportion of area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>31</td>
<td>64</td>
<td>41</td>
</tr>
<tr>
<td>1.3</td>
<td>28</td>
<td>64</td>
<td>41</td>
</tr>
<tr>
<td>3.3</td>
<td>23</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>5.3</td>
<td>18</td>
<td>57</td>
<td>33</td>
</tr>
<tr>
<td>7.3</td>
<td>17</td>
<td>56</td>
<td>31</td>
</tr>
<tr>
<td>9.3</td>
<td>15</td>
<td>56</td>
<td>31</td>
</tr>
<tr>
<td>11.3</td>
<td>13</td>
<td>54</td>
<td>29</td>
</tr>
<tr>
<td>13.3</td>
<td>12</td>
<td>49</td>
<td>24</td>
</tr>
<tr>
<td>15.3</td>
<td>10</td>
<td>43</td>
<td>18</td>
</tr>
<tr>
<td>17.3</td>
<td>7</td>
<td>35</td>
<td>13</td>
</tr>
<tr>
<td>19.3</td>
<td>3</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>21.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* The average proportion of heartwood diameter to sectional diameter of each disk.

Table 12. Distribution of moisture content in the wood of sugi 2 (%)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average of heartwood</th>
<th>Average of wood</th>
<th>Average of wood*</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>162 190 190 147 124 74 191 311 343 303 283</td>
<td>148</td>
<td>286</td>
<td>218</td>
<td>156</td>
</tr>
<tr>
<td>1.3</td>
<td>146 151 112 86 89 134 146 219 287 230 251</td>
<td>117</td>
<td>253</td>
<td>188</td>
<td>147</td>
</tr>
<tr>
<td>5.3</td>
<td>154 123 70 63 89 176 240 256 217 223</td>
<td>100</td>
<td>230</td>
<td>168</td>
<td>158</td>
</tr>
<tr>
<td>7.3</td>
<td>125 69 53 76 186 230 241 209 207</td>
<td>81</td>
<td>215</td>
<td>159</td>
<td>164</td>
</tr>
<tr>
<td>9.3</td>
<td>186 101 64 73 145 217 232 226 214</td>
<td>106</td>
<td>207</td>
<td>166</td>
<td>174</td>
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<tr>
<td>11.3</td>
<td>111 104 63 128 236 252 222 228</td>
<td>93</td>
<td>213</td>
<td>170</td>
<td>174</td>
</tr>
<tr>
<td>13.3</td>
<td>145 130 95 62 184 223 209 203</td>
<td>108</td>
<td>205</td>
<td>170</td>
<td>183</td>
</tr>
<tr>
<td>15.3</td>
<td>142 111 76 145 208 185 185</td>
<td>110</td>
<td>181</td>
<td>157</td>
<td>156</td>
</tr>
<tr>
<td>17.3</td>
<td>148 112 83 176 205 187</td>
<td>114</td>
<td>189</td>
<td>164</td>
<td>175</td>
</tr>
<tr>
<td>19.3</td>
<td>103 57 143 195 191</td>
<td>80</td>
<td>176</td>
<td>157</td>
<td>162</td>
</tr>
<tr>
<td>21.3</td>
<td>55 88 171 179</td>
<td>72</td>
<td>175</td>
<td>154</td>
<td>147</td>
</tr>
<tr>
<td>23.3</td>
<td>104 195 185</td>
<td>104</td>
<td>190</td>
<td>189</td>
<td>161</td>
</tr>
<tr>
<td>25.3</td>
<td>155 201 188</td>
<td>–</td>
<td>178</td>
<td>178</td>
<td>188</td>
</tr>
<tr>
<td>26.3</td>
<td>239</td>
<td>–</td>
<td>239</td>
<td>239</td>
<td>189</td>
</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>107</td>
<td>216</td>
<td>177</td>
<td>167</td>
</tr>
</tbody>
</table>

Min.-Max. 53-343

* Weighted average calculated with the proportion of heartwood area (cf. Table 15).
moisture content of heartwood is generally low in the coniferous trees, that of the sugi 1 heartwood is extraordinarily high, 132% on the average. In addition, the values are greatly vary in different parts of the heartwood; at the 5.3 and 7.3-m heights the moisture content is relatively low except in the pith, while at the 0.3 and 1.3-m heights it is very high. The intermediate wood between sapwood and heartwood, seems to have comparatively low moisture contents. The average basic density is 409 kg/m³, ranging from 314 to 490 kg/m³ (Table 9). In general, the wood from the upper parts of the tree appears to have a high density. The annual ring width is 2.84 mm on the average, ranging from 1.5 to 5.7 mm. Table 10 also indicates the diameter growth was large in the young stage and small in the final stage. As shown in Table 11, the heartwood, being a very dark brown color in its green state, accounts for over 60% of the wood present when measured by the diameter and about 40% when measured by the area up to the height of 3.3 m. The heartwood proportion gradually decreases with height, falling to 0% at 21.3 m and above.

The physical properties of the wood of sugi 2 are shown in Tables 12, 13, 14, and 15. It can be said that sugi 2 has very similar properties to sugi 1. The moisture content is 177% on the average, a little higher than that of sugi 1, with the maximum given at 343% (Table 12). The average moisture content in the heartwood, likewise, exceeds 100%, and the distribution of moisture content values is widely scattered. From these results, the timber of the sugi trees in this plantation can be considered a kind of wetwood because they seem to have a characteristic high moisture content in their heartwood. The average basic density is 371 kg/m³ (Table 13), a little lower than that of sugi 1. The lower density figures are obtained from the lower part of the wood. The annual ring width is 2.75 mm on the average, with a wide distribution, ranging from 0.7 to 8.3 mm (Table 14). The wider width

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>359</td>
<td>317</td>
<td>305</td>
</tr>
<tr>
<td>1.3</td>
<td>328</td>
<td>314</td>
<td>343</td>
</tr>
<tr>
<td>5.3</td>
<td>388</td>
<td>326</td>
<td>356</td>
</tr>
<tr>
<td>7.3</td>
<td>330</td>
<td>331</td>
<td>396</td>
</tr>
<tr>
<td>9.3</td>
<td>358</td>
<td>357</td>
<td>409</td>
</tr>
<tr>
<td>11.3</td>
<td>342</td>
<td>375</td>
<td>413</td>
</tr>
<tr>
<td>13.3</td>
<td>406</td>
<td>377</td>
<td>400</td>
</tr>
<tr>
<td>15.3</td>
<td>397</td>
<td>431</td>
<td>429</td>
</tr>
<tr>
<td>17.3</td>
<td>398</td>
<td>432</td>
<td>402</td>
</tr>
<tr>
<td>19.3</td>
<td>486</td>
<td>457</td>
<td>399</td>
</tr>
<tr>
<td>21.3</td>
<td>461</td>
<td>381</td>
<td>383</td>
</tr>
<tr>
<td>23.3</td>
<td>399</td>
<td>374</td>
<td>441</td>
</tr>
<tr>
<td>25.3</td>
<td>391</td>
<td>435</td>
<td>413</td>
</tr>
<tr>
<td>26.3</td>
<td>435</td>
<td>435</td>
<td>320</td>
</tr>
<tr>
<td>Grand average</td>
<td>371</td>
<td>343</td>
<td></td>
</tr>
<tr>
<td>Min.-Max.</td>
<td>234-486</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 14. Distribution of annual ring width in the wood of sugi 2 (mm)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>4.1 7.3 5.3 2.8 3.8 2.2 2.5 2.0 2.3 1.8 1.3</td>
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</tr>
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<td>2.6</td>
</tr>
<tr>
<td>3.3</td>
<td>6.7 5.4 2.8 2.0 2.3 1.5 1.5 1.7 1.1 0.9</td>
<td>2.6</td>
</tr>
<tr>
<td>5.3</td>
<td>6.9 6.7 3.1 2.2 2.0 1.4 1.4 1.5 0.8 0.8</td>
<td>2.7</td>
</tr>
<tr>
<td>7.3</td>
<td>7.4 4.1 2.6 2.1 1.4 1.5 1.6 1.0 0.8</td>
<td>2.5</td>
</tr>
<tr>
<td>9.3</td>
<td>6.8 5.3 3.2 2.0 1.4 1.2 1.4 1.2 0.7</td>
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<tr>
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<td>6.7 3.8 1.9 1.6 1.8 1.6 1.1 1.0</td>
<td>2.4</td>
</tr>
<tr>
<td>13.3</td>
<td>6.5 4.1 3.2 2.2 2.0 1.8 1.4 0.8</td>
<td>2.8</td>
</tr>
<tr>
<td>15.3</td>
<td>4.7 3.8 2.7 2.3 2.3 1.5 1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>17.3</td>
<td>3.6 3.9 3.2 2.9 1.9 1.3</td>
<td>2.8</td>
</tr>
<tr>
<td>19.3</td>
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<td>2.9</td>
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<td>21.3</td>
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<td>3.4</td>
</tr>
<tr>
<td>23.3</td>
<td>5.1 3.8 1.7</td>
<td>3.5</td>
</tr>
<tr>
<td>25.3</td>
<td>3.5 1.9</td>
<td>2.7</td>
</tr>
<tr>
<td>26.3</td>
<td>2.8</td>
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</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>2.75</td>
</tr>
<tr>
<td>Min.-Max.</td>
<td></td>
<td>0.7-8.3</td>
</tr>
</tbody>
</table>

Table 15. Distribution of heartwood proportion in the wood of sugi 2

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Annual ring number of heartwood</th>
<th>Proportion of diameter* (%)</th>
<th>Proportion of area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>26</td>
<td>69</td>
<td>49</td>
</tr>
<tr>
<td>1.3</td>
<td>24</td>
<td>69</td>
<td>48</td>
</tr>
<tr>
<td>5.3</td>
<td>19</td>
<td>69</td>
<td>48</td>
</tr>
<tr>
<td>7.3</td>
<td>16</td>
<td>65</td>
<td>42</td>
</tr>
<tr>
<td>9.3</td>
<td>14</td>
<td>64</td>
<td>41</td>
</tr>
<tr>
<td>11.3</td>
<td>13</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>13.3</td>
<td>12</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>15.3</td>
<td>11</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>17.3</td>
<td>10</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>19.3</td>
<td>8</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>21.3</td>
<td>6</td>
<td>44</td>
<td>20</td>
</tr>
<tr>
<td>23.3</td>
<td>2</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>25.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* The average proportion of heartwood diameter to sectional diameter of each disk.
### Table 16. Distribution of moisture content in the wood of the hinoki (%)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average of heartwood</th>
<th>Average of sapwood</th>
<th>Average of wood</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>37 35 34 36 38 40 39 101 184 175 207</td>
<td>37</td>
<td>167</td>
<td>88</td>
<td>99</td>
</tr>
<tr>
<td>1.3</td>
<td>34 33 34 33 34 37 70 169 162 176</td>
<td>34</td>
<td>144</td>
<td>79</td>
<td>107</td>
</tr>
<tr>
<td>3.3</td>
<td>35 34 32 33 33 37 43 157 156 167</td>
<td>35</td>
<td>160</td>
<td>88</td>
<td>107</td>
</tr>
<tr>
<td>5.3</td>
<td>36 33 33 34 35 42 138 159 176</td>
<td>36</td>
<td>158</td>
<td>87</td>
<td>104</td>
</tr>
<tr>
<td>7.3</td>
<td>34 33 34 34 35 35 124 158 167</td>
<td>34</td>
<td>150</td>
<td>85</td>
<td>112</td>
</tr>
<tr>
<td>9.3</td>
<td>36 33 34 35 36 116 155 174</td>
<td>35</td>
<td>148</td>
<td>85</td>
<td>119</td>
</tr>
<tr>
<td>11.3</td>
<td>32 32 35 34 107 144 157</td>
<td>33</td>
<td>136</td>
<td>86</td>
<td>125</td>
</tr>
<tr>
<td>13.3</td>
<td>37 34 34 92 158 176</td>
<td>35</td>
<td>142</td>
<td>96</td>
<td>117</td>
</tr>
<tr>
<td>15.3</td>
<td>33 33 58 149 174</td>
<td>41</td>
<td>162</td>
<td>121</td>
<td>125</td>
</tr>
<tr>
<td>17.3</td>
<td>33 50 118 154</td>
<td>42</td>
<td>136</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>19.3</td>
<td>51 93 119</td>
<td>51</td>
<td>106</td>
<td>103</td>
<td>127</td>
</tr>
<tr>
<td>21.3</td>
<td>80 88</td>
<td>-</td>
<td>84</td>
<td>84</td>
<td>127</td>
</tr>
<tr>
<td>22.3</td>
<td>73</td>
<td>-</td>
<td>73</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td>23.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>36</td>
<td>142</td>
<td>92</td>
<td>114</td>
</tr>
</tbody>
</table>

Min.-Max. | 32-207 |

* Weighted average calculated with the proportion of heartwood area (cf. Table 19).

### Table 17. Distribution of basic density in the wood of the hinoki (kg/m³)

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>404 433 409 404 401 400 407 392 360 380 355 395 385</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>440 438 426 396 394 402 384 376 384 379</td>
<td>402</td>
<td>335</td>
</tr>
<tr>
<td>3.3</td>
<td>462 459 457 423 441 433 423 385 405 399</td>
<td>429</td>
<td>356</td>
</tr>
<tr>
<td>5.3</td>
<td>483 485 417 398 424 424 412 390 397 385</td>
<td>421</td>
<td>347</td>
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<tr>
<td>7.3</td>
<td>487 479 461 408 372 381 398 394 396</td>
<td>420</td>
<td>373</td>
</tr>
<tr>
<td>9.3</td>
<td>533 507 455 388 385 372 378 374</td>
<td>424</td>
<td>342</td>
</tr>
<tr>
<td>11.3</td>
<td>571 493 447 384 383 368 362</td>
<td>430</td>
<td>334</td>
</tr>
<tr>
<td>13.3</td>
<td>570 495 467 385 397 395</td>
<td>452</td>
<td>382</td>
</tr>
<tr>
<td>15.3</td>
<td>549 536 460 425 387</td>
<td>471</td>
<td>336</td>
</tr>
<tr>
<td>17.3</td>
<td>594 581 491 471</td>
<td>534</td>
<td>431</td>
</tr>
<tr>
<td>19.3</td>
<td>540 562 537</td>
<td>546</td>
<td>409</td>
</tr>
<tr>
<td>21.3</td>
<td>579 550</td>
<td>565</td>
<td>480</td>
</tr>
<tr>
<td>22.3</td>
<td>600</td>
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<td>600</td>
</tr>
<tr>
<td>23.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>438</td>
<td>383</td>
</tr>
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</table>

Min.-Max. | 355-600 |
Table 18. Distribution of annual ring width in the wood of the hinoki

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Section of annual ring number from pith</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>2.8 3.1 4.1 3.8 4.5 2.6 2.3 1.8 1.9 2.2 2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>1.3</td>
<td>3.0 4.1 3.8 4.1 2.4 1.7 1.5 1.7 1.9 2.1</td>
<td>2.6</td>
</tr>
<tr>
<td>3.3</td>
<td>3.0 4.2 4.0 3.9 2.4 1.8 1.6 1.7 1.8 1.7</td>
<td>2.6</td>
</tr>
<tr>
<td>5.3</td>
<td>2.7 4.6 3.6 3.2 1.9 1.8 1.9 1.7 1.9</td>
<td>2.6</td>
</tr>
<tr>
<td>7.3</td>
<td>4.6 4.2 3.1 2.4 1.9 2.1 2.2 1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>9.3</td>
<td>3.3 4.4 4.0 2.8 2.6 2.3 2.1 1.8</td>
<td>2.9</td>
</tr>
<tr>
<td>11.3</td>
<td>3.3 3.8 3.6 2.9 2.9 2.4 2.1</td>
<td>3.0</td>
</tr>
<tr>
<td>13.3</td>
<td>3.4 3.7 3.6 3.4 2.7 2.3</td>
<td>3.2</td>
</tr>
<tr>
<td>15.3</td>
<td>2.9 3.5 4.7 2.6 2.9</td>
<td>3.3</td>
</tr>
<tr>
<td>17.3</td>
<td>3.1 3.6 3.8 3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>19.3</td>
<td>2.9 3.3 3.6</td>
<td>3.3</td>
</tr>
<tr>
<td>21.3</td>
<td>2.5 3.3</td>
<td>2.9</td>
</tr>
<tr>
<td>22.3</td>
<td>2.5 2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>23.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Grand average</td>
<td></td>
<td>2.86</td>
</tr>
<tr>
<td>Min.-Max</td>
<td></td>
<td>1.5-4.7</td>
</tr>
</tbody>
</table>

Table 19. Distribution of heartwood proportion in the wood of the hinoki

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Annual ring number of heartwood</th>
<th>Proportion of diameter* (%)</th>
<th>Proportion of area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>33</td>
<td>78</td>
<td>61</td>
</tr>
<tr>
<td>1.3</td>
<td>29</td>
<td>77</td>
<td>59</td>
</tr>
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<td>3.3</td>
<td>27</td>
<td>76</td>
<td>58</td>
</tr>
<tr>
<td>5.3</td>
<td>25</td>
<td>76</td>
<td>58</td>
</tr>
<tr>
<td>7.3</td>
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<td>75</td>
<td>56</td>
</tr>
<tr>
<td>9.3</td>
<td>23</td>
<td>75</td>
<td>56</td>
</tr>
<tr>
<td>11.3</td>
<td>22</td>
<td>70</td>
<td>49</td>
</tr>
<tr>
<td>13.3</td>
<td>16</td>
<td>66</td>
<td>43</td>
</tr>
<tr>
<td>15.3</td>
<td>11</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>17.3</td>
<td>7</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>19.3</td>
<td>3</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>21.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* The average proportion of heartwood diameter to sectional diameter of each disk.
is generally shown in the young stage, while the width in the outer areas is extremely narrow. As shown in Table 15, the proportion of heartwood exceeds 60% when measured by the diameter up to a height of 13.3 m. It has a very dark brown color in its green state, and its proportion gradually decreases as one goes upwards with the heartwood entirely disappearing at the height of 25.3 m.

The distributions of moisture content, basic density, annual ring width and the proportion of heartwood in the wood of the hinoki are presented in Tables 16, 17, 18, and 19, respectively. As shown in Table 16, the average moisture content in the heartwood and sapwood is 36% and 142%, respectively, which indicates that the hinoki tree can be called a normal one. The basic density is 438 kg/m³ on the average, higher than that of sugi trees. In general, the density of sapwood is lower than that of heartwood, which has levels as high as 600 kg/m³ in the upper parts (Table 17). The average annual ring width is 2.86 mm. The range is from 1.5 to 4.7 mm, showing less deviation than in the sugi. However, the growth in the early stage was larger and in the final stage was smaller, as was the case with the sugi (Table 18). Table 19 indicates that the proportion of heartwood is considerably high, showing figures of over 70% when measured by the diameter up to a 11.3-m height. The heartwood disappears at a height of 21.3 m.

Discussion

It is evident that the Wakayama Experiment Forest is a suitable area for planting sugi and hinoki on account of favorable climatic conditions such as an annual mean temperature of 15.4°C and yearly precipitation of over 3,700 mm mainly falling in the growing season, as well as good soil conditions. The soils have generally a thick A horizon of loamy texture with crumb structure, a satisfactory humus content and a fairly high gravel content. However, those of the sugi plantation surveyed at Plot 1 were found to be the BC type (slightly dry brown forest soils). Sugi, preferring humid circumstances, is usually planted in the soils of BF or BF type (slightly wet or wet brown forest soils). Compared with the sugi trees in the Hiyama Experiment Forest, southern Hokkaido, the trees in the Wakayama Experiment Forest are 6 to 9 m higher than the first class trees in the Hiyama Experiment Forest at the same age of 30 years. Also when compared with other trees produced in the famous sugi districts such as Ibaragi, Toyama and Gifu or Tottori Prefectures, one finds that those in the Wakayama Experiment Forest are superior in growth. In addition, the hinoki trees grown in the Wakayama Experiment Forest also show remarkable growth, compared to the 91-year-old hinoki trees which have an average height of 22.7 m, planted in Gifu Prefecture. Moreover, the 79-year-old hinoki trees planted in Otaru, Hokkaido, a very cold region, have an average height of only 17.8 m, while Miyoshi has shown that 36 naturally growing hinoki trees from 75 to 325 years old collected from various districts have heights from 14 to 31 m and D.B.H. from 21 to 55 cm.

Concerning the physical properties of the wood, Fig. 5 shows the moisture content distributions of sugi 1, sugi 2, the hinoki, and the arakashi at a height of 1.3 m. With the hinoki, the difference in the moisture content between the heart- and sapwood is conspicuous, while with the arakashi the distribution is on the whole approximately 60%, including the heartwood. With the sugi trees, the heartwood in both has a high moisture content with wide deviation in values, and the intermediate wood between the heart- and
sapwood seems to have somewhat a lower moisture content as is found in todomatsu (*Abies sachalinensis*), studied for its properties as a wetwood\(^7\)\(^8\). According to Yazawa and Fukazawa’s studies, the moisture content in the black heartwood of the bigger sugi trees grown at the first site class is generally higher than that in the red heartwood of stunted trees\(^9\). Yazawa, who has divided sugi trees into two classes, A and B, according to the moisture content in the heartwood, has reported that sugi is one of the coniferous trees having the highest moisture content in its heartwood\(^27\)\(^30\). Though the cause and mechanism of the high moisture content in the heartwood of some coniferous trees have not been fully elucidated, its occurrence seems to be connected with enviromental circumstances rather than genetic factors. Furthermore, the moisure is thought to be derived from the soil through the roots rather than from the sapwood or through rain entering through withered branches, judging from the concentration and the chemical composition of inorganic matter in the sap taken from the heartwood\(^7\)\(^8\)\(^24\).

As shown in Fig. 6, the basic density of the arakashi wood is markedly high, being 760
kg/m³ on the average with a wide range, followed by the hinoki, sugi 1, and sugi 2. Comparing the basic density of the sugi trees the values from sugi 1 and 2 are a little higher than those from the sugi trees produced in Ibaragi, Chiba, and Tottori Prefectures, and considerably higher than those from the sugi trees grown at the Hiyama Experiment.
The wood of the hinoki is also higher in its basic density than that planted in Gifu Prefecture and Otaru. The comparison of the annual ring width in sugi 1, sugi 2, the hinoki, and the arakashi at a height of 1.3 m is presented in Fig. 7. The width distribution of the arakashi is uniform with its rings being about 1 mm apart, while the ring widths of planted trees that were examined, especially sugi 2, varied considerably wider widths in the early stages, caused mainly by a lack of tending, such as pruning. According to Fukazawa's study, the average widths for sugi trees are from 1.45 mm to 5.17 mm, with wide coefficients of
variation of 30 to 40% for each tree\textsuperscript{23}. Contrary to this, the width variation found in the hinoki examined is comparatively less, even though it was grown under the same conditions and with the same tending as the sugi trees. Yazawa and Fukazawa have shown that the average annual ring width of hinoki trees is from 1.26 to 2.17 mm (calculated from the annual ring density\textsuperscript{28}), narrower than of hinoki trees in the Wakayama Experiment Forest.

Meanwhile, Ueda has studied the modulus of elasticity (MOE) of sugi and hinoki standing trees planted in the Wakayama Experiment Forest and sugi in the Hiyama Experiment Forest.\textsuperscript{21} The values of MOE for hinoki trees are the highest, ranging from 100 to 160 tons/cm\textsuperscript{2}, followed by sugi trees whose values ranged from 60 to 110 tons/cm\textsuperscript{2} in the former Experiment Forest and from 50 to 60 tons/cm\textsuperscript{2} in the latter Experiment Forest.

**Conclusion**

To summarize the results, the sugi and hinoki trees planted in the Wakayama Experiment Forest grew very well, and their physical properties were excellent, compared with the trees produced in other districts. Though the hinoki tree was a little inferior to the sugi tree in its growth, it was quite superior to the sugi tree in its wood quality, as for instance its higher basic density and comparatively uniform annual ring width. However, the wider deviation of the annual ring width found in the sugi seems to have been caused by the lack of tending. A fixed annual ring width of the wood should be always maintained throughout the growing period by constant thinning and pruning based on a management plan. The high moisture content and its uneven distribution often found in the sugi heartwood, the cause of which has not been clearly elucidated, is a defect. Sugi is considered a kind of wetwood, and like other wetwoods, utilization could be problematic because of difficulties in drying schedule and the distortion of wood. It is to be noted that frost cracks are sometimes observed in the standing trees in cold regions.

At present, in the Wakayama Experiment Forest the forests are being carefully tended and well managed. The project to convert to an artificial multi-storied forest and the high-value timber producing forest is underway.

**Literature Cited**

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北海道大学和歌山地方演習林は、暖帯林における試験研究と学生の実習を目的に、約430haの森林を購入して、1925（大正14）年3月に設立された。本林は森林植物帯と暖帯北部に位置し、シイ・カシを主とする照葉樹の二次林からなり、年平均気温15.4℃、年降水量3,700mm以上（1971―1980年の観測平均値）にも達する温暖多雨の気候である。1928（昭和3）年に編成された第1次施業に基づいて、スギ・ヒノキ林施業技術体系の確立を主要テーマに、これまで毎年造林を実施してきた。戦中・戦後の一時期の止むを得ない中断はあるが、今や全林の75％がスギ・ヒノキの造林地となっている。残りの森林は、大森山保存林（59ha）を含む各種の特定試験林である。現在は、1984（昭和59）年に編成された新長期計画に基づいて、人工林に対して無節柱用材の生産。良質大径材生産あるいは間伐と樹下植栽による複層林の造成等、各種の新しい実験が精力的に実施されている。

本研究では、和歌山地方演習林の土壌の性質と植栽木の生長および性質を把握する目的で、まず本林5林班に1936（昭和11）年に植栽されたスギおよびヒノキの造林地と16林班の照葉樹見本林の3ヶ所の現地土壌調査を行った。1988年春には森林調査とともに、5林班内のスギ2本（スギ1、スギ2）とヒノキ1本および16林班のアラカシ1本を伐採して、その生長経過を解析した。つぎにこれらの材の基本的物理性を知るため、各円板から醚を通る2本の直交する2cm幅の細片板を作り、さらに5年毎に小ブロックを作製して、生材含水率、容積密度数、年輪幅、心材率の分布を調べた。

これらの結果は次の通りである。

1. 標準地調査の結果、1988年の時点でスギ造林地（Plot 1）はha当たり本数1,000本、蓄積685㎥, 平均胸高22.6m, 同胸高直径28.5cmで、ヒノキ造林地（Plot 2）は、本数1,200本、蓄積748㎥, 平均胸高21.7m, 同胸高直径26.5cmであり、いずれも現在はごく最近実施したスギの樹下植栽により、二段林になっている。一方16林班の照葉樹林（Plot 3）は、本数2,400本、蓄積404㎥, 平均胸高は11.7mで範囲は6mから28mに及び、平均胸高直径は12.8cmであった。その主要樹種はアラカシ（Quercus glauca）, ツクバネガシ（Q. paucidentata）, ウラジロガシ（Q. stenophylla）, ウプラジイ（Shiia cuspidata）, イヌガシ（Litsea aciculata）, ウシカバ（Ilex sageroki var. longipedunculata）, バリバリノキ（Actinodaphne acuminata）, サカキ（Cleyera ochracea）, ムクロシ（Sophus mukurossi）等18種の広葉樹であった。

2. 土壌はいずれも褐色森林土であり、スギ造林地と照葉樹林地はやや乾性のBcタイプ、ヒノキ造林地は適潤性のBbタイプであった。一般にスギは湿性を好むため、低所に植えられ、今回調査した造林地の場合も標高520mのところにスギ、その上部560mの場所にヒノキが植え
されているが、500 m を超えた森林には湿性土壌（Bw, Bf タイプ）は見られず、むしろスギ造
林地の方が乾燥していた。肉眼により A0, A, B 層に分けられ、その性質を調べると、A0 の厚
さは照葉樹林（8 cm）＞ ヒノキ林（4 cm）＞ スギ林（2.5 cm）の順であった。一般には広葉樹
の落葉は分解が早いので、A0 層の厚さは針葉樹林より薄いのが普通であるが、この林地は常
緑広葉樹からなり、しかも立木密度が高く林内が暗いため、8 cm という大きな値が得られたも
のと推測される。A 層の厚さは、スギ林と照葉樹林の場合ともに 40 cm、ヒノキ林では 19 cm で
あり、その土壌はいずれも膨軟で通気の腐植土となカリの量が少な、壊土質であった。また
B 層はともに 45 cm 以上と深く、容積重の大きな土壌で水分は比較的少なく、土壌相におけ
る固相の割合が 33〜43% と高かった。しかし基密度は硬度計で 15〜17 mm を示し、林木はその
根を土中に充分伸ばすことができ、適切の透水性と通気性もあるので、樹木の生育に適した土
壌といえよう。

3. 供試木は 53〜54 年生の造林木 3 本（スギ 2 本、ヒノキ 1 本）と天然のアラカシ 1 本であ
ったが、アラカシは胸高直 9.5 cm で、年輪が極めて密で樹幹解析は困難であり、とり止めた。
1.3 m の高さの円板の年輪数は 50 を数えた。造林木はいずれもよく生育しており、スギ 1 ではほ
ば平均木であり、スギ 2 とヒノキは胸高直径では平均に近いが、樹高はそれより 2 ないし 4 m
高いものであった。その材積は、スギ 1, 2, ヒノキでそれぞれ 0.7126, 0.7856, 0.6265 m³で、
平均堆生長量はそれぞれ 0.0123, 0.0136, 0.0109 m³であった。しかしいずれも比較的初期の段
階での生育が著しく、例えばスギ 2 では 10 年で 7.3 m の高さに、20 年で 14.5 m の樹高に達し
ていた。しかし最近の生育は衰え、樹高生長率でヒノキはわずか 1.6 %、スギの場合は 1 %以下
となっていた。また材積生長率では、スギ 1 とヒノキは 4 %台であるのに対し、スギ 2 は 2 %
を割っていた。これは周辺環境の影響もあるとは思うが、スギ 2 は初期生長が大きいだけ、逆
に最近の生育低下が顕著になっている。

一方、樹幹解析では各円板の半径を平均化し、正円として生長経過を調べるので、円形指
数（各円板における長径に対する短径の割合）を算出してみた。その結果、平均でヒノキは 1.05
と円に近く、スギは 1.13 と 1.16 でともに稍円形であった。

4. 生材平均含水率は、スギ 1 と 2 ではそれぞれ 159 と 177% であり、材材のもの平均でも
132 および 107% と著しく高かった。しかもその分布は極めてバラついていた。これに対してヒ
ノキの場合は平均 92% で、材材は 36%、辺材は 14% であった。またアラカシの 1.3 m 高の円
板では心・辺材の水分の差はなく、大体 60% 前後であった。このスギ材材の高含水率の原因に
ついてはまだ十分に解明されていないが、各地で生産されているスギでもしばしば見られ、
生長のよいもの程一般に材材含水率が高い傾向にある。これまでのトドマツ水木材材の研究から、
それは品種よりもむしろ立地に由来するのではないかと考えられる。和歌山地方演習林産スギ
の場合には立木の凍裂・腐朽等の恐れはないが、利用に際して乾燥やうすい注意が必要であ
らう。
5. 容積密度数は、スギ1と2では平均409と371kg/m³であったのに対し、ヒノキの場合は438kg/m³と比較的高かった。一般に木の中央部および上部の容積密度数は高く、逆に辺材部が低かった。一方アラカシではその平均は760kg/m³と極めて高く、分布も大きくバラついていた。

6. スギ1、2およびヒノキの平均年輪幅は、それぞれ2.84、2.75および2.86mmであったが、いずれもその分布のバラつきは著しく、とくにスギ2の場合は最小の0.7mmから最大の8.3mmまで範囲は広がり、初期肥大生長が著しかったことを示している。これは戦中・戦後の手入れ不足に起因しているものと思われる。しかし有名林業地といわれる箇所で調査したスギの例でも、やはり初期の肥大生長は大であり、年輪幅の変動係数は30-40％にもなっていった。和歌山地方檀釗林では、現在造林木に対し常に一定の年輪幅を保つよう育林に意を注いでいる。これに対し天然のアラカシでは、1.3m高の円板の場合平均1mm以下で、しかもそのバラつきは殆んど見られなかった。

7. スギの心材の色調は濃茶褐色であったのに対し、ヒノキのそれは淡色で辺・心材の色の差は僅かであった。心材の各円板に占める割合は、スギの下部では直径比で60-70％であるのに対し、ヒノキの場合11.3mまでは70％を超えていた。しかし上部ではいずれも心材は少なくなり、スギ1、2およびヒノキでそれぞれ21.3、25.3および21.3m以上で心材は全く見られなかった。

8. 以上の結果から、和歌山地方檀釗林は森林の育成条件に恵まれており、スギ・ヒノキの造林は極めて有意義である。両者の生長・材質とも有名林業地のものと比較して遜色がなく、とくにヒノキは材質的に優れていた。今後とも人工林に対し多様な施業試験を展開し、高価値優良材を生産するよう努力を続けていくことが期待される。