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

By

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和歌山地方演習林産スギ・ヒノキ植栽木の生長と材質

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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.

Contents

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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 millon 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 each[1]. 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, Yazawa[26,27], Miyoshi[12], Hirai[3~5], Sakata and Saeki[16], Yazawa and Fukazawa[28,29], and Fukazawa[2] have described them in detail. Meanwhile, there also have been many general research books published on sugi and hinoki[13~15,17~20].

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 Forest[10]

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

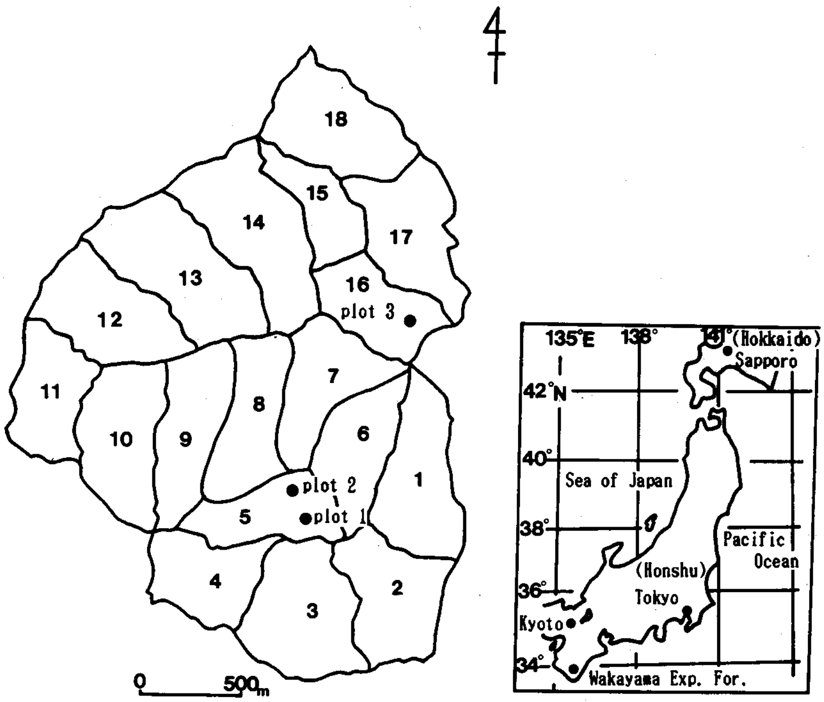

Fig. 1. Location of experimental sites in the Wakayama Experiment Forest.
Note: The figures are the compartment Nos.

in Fig. 1, it is situated at 135°40′ east longitude and 33°40′ north latitude, belonging adminstratively to Kozagawa Town, Wakayama Prefecture. In terms of geology, the area exists on Paleogenic strata classified into the Muro 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

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Mean temperature (℃)	5.3	6.3	14.6	14.6	17.5	21.8	25.0	25.5	22.9	17.7	12.6	7.5	15.4
Mean max. temperature (℃)	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 (℃)	−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	376.8	497.8	411.0	523.5	408.5	243.4	184.9	121.1	313.4 (3,761)*1
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 (1,701)*1

*1 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 *Shiia* 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 knotfree-faced boxed heart timber for Japanese houses[11]. 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 2. Outline of the experimental sites

Plot	Site (Compartment)	Forest	Year of plantation	Elevation (m)	Slope and direction	Planting number (seedlings/ha)	Living number (Stems/ha)	Height (m) average / min.-max.	S.D.*2	D.B.H. (cm) average / min.-max.	S.D.	Growing stock (m^3/ha)
1 *1	5	Sugi artificial forest	1936	520	20°S	4,650	1,000	22.6 / 19-27	2.59	28.5 / 18-37	6.35	685
2 *1	5	Hinoki artificial forest	1936	560	19°S	4,650	1,200	21.7 / 19-24	1.44	26.5 / 16-32	4.52	748
3	16	Natural secondary broad-leaved forest	—	320	38°SE	—	2,400	11.7 / 6-28	6.28	12.8 / 6-30	7.16	404

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.

sugi plantation of Compartment 5, Plot 2 in the hinoki plantation of the same Compartment and Plot 3 in the natural secondary broad-leaved forest of Compartment 16. Plot 1 is located at a mean elevation of 520 m and faces southward at a slope angle of 20°. Plot 2 is situated upward from the sugi plantation at a mean elevation of 560 m and faces southward at a slope angle of 19°. According to the afforestation ledger and Management Materials[10], sugi and hinoki seeds, purchased from a nearby forest owner, were bred and nursed in the temporary nursery in the forest for two or three years. Both kinds of seedlings were planted at the rate of 4,650 each per hectare in 1936, but tending, including weeding and pruning, was inadequately carried out due to the confusion and labor shortage during and immediately after the War. The first and second thinnings as improvement cutting were practiced in 1955 and 1962, respectively. Based on the new management plan, the two artificial forests now are being changed to the multi-storied forests (at present 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 m^2 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 m^3 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 m^3 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. *longepedunculata*, *Actinodaphne acuminata*, *Cleyera ochnacea*, and *Sapindus mukurossi*. 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 m^3 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_0 layer, A 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-cm 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 3. Trees used for the experiments

Tree	Site (Compartment)	Height (m)	D.B.H. (cm)	Age (yr)
Sugi 1	5	23.6	28.4	53
Sugi 2	5	26.8	28.5	54
Hinoki	5	23.8	25.7	53
Arakashi	16	11.9	9.5	50* <

* 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 A_0 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 A_0 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 A_0 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 4. Properties of soils

Plot	Site (Compartment)	Forest	Soil type	Horizon	Depth (cm)	Thickness (cm)	Color: with Munsell	Color: by naked eye	Hardness: tester (mm)	Hardness: consistency
1	5	Sugi planted in 1936	B_C	A_0		2.5	10YR2/3	brownish black	3	loose
				A	0-40	40	7.5YR2/3	very dark brown	14	soft
				B	40-85	45<	10YR4/4	brown	17	slightly hard
2	5	Hinoki planted in 1936	B_D	A_0		4.0	10YR3/3	dark brown	3	loose
				A	0-19	19	10YR3/4	dark brown	8	loose
				B	19-70	51<	10YR5/6	yellowish brown	15	slightly hard
3	16	Natural secondary broad-leaved	B_C	A_0		8.0	7.5YR2/3	very dark brown	4	loose
				A	0-40	40	10YR3/3	dark brown	7	loose
				B	40-90	50<	10YR5/4	dull yellowish brown	15	slightly hard

aeration. The gravels consist of breccia of some 5 cm in size, and are contained even in the A_0 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 A_0 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

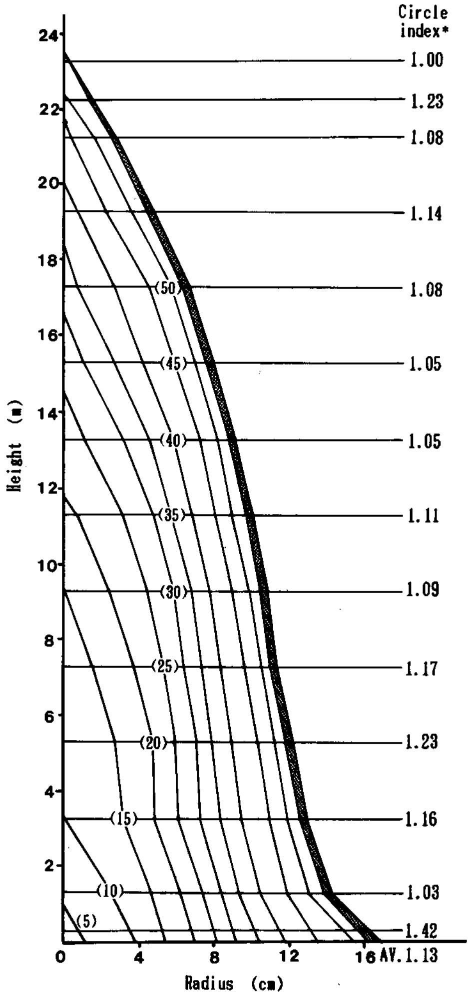

Fig. 2. Stem analysis of sugi 1.

* The proportion of the longer diameter to the shorter one on the tree-disk at different heights.

under natural condition

Structure	Soil class	Humus content	Gravel content (%)	Apparent specific gravity		Moisture content based on (%)		Distribution of three-phase (vol. %)			Porosity (vol. %)
				fresh soil	dried soil	fresh soil	dried soil	solid	liquid	gas	
–	–	very rich	21	0.57	0.30	48.2	93.0	15	28	57	85
crumb	SiL	rich	15	0.99	0.59	40.5	68.2	25	39	36	75
crumb	L	containing	10	1.46	1.00	32.1	47.4	37	45	18	63
–	–	very rich	0	0.45	0.12	74.0	284.1	6	33	61	94
crumb	L	containing	32	1.15	0.66	43.3	76.3	28	50	22	72
crumb	L	scarce	32	1.37	0.89	35.7	55.4	33	49	18	67
–	–	very rich	15	0.43	0.14	67.1	203.9	7	29	64	93
crumb	SiL	rich	32	1.12	0.76	32.1	47.3	32	36	32	68
crumb	SL	scarce	23	1.50	1.16	22.9	29.7	43	34	23	57

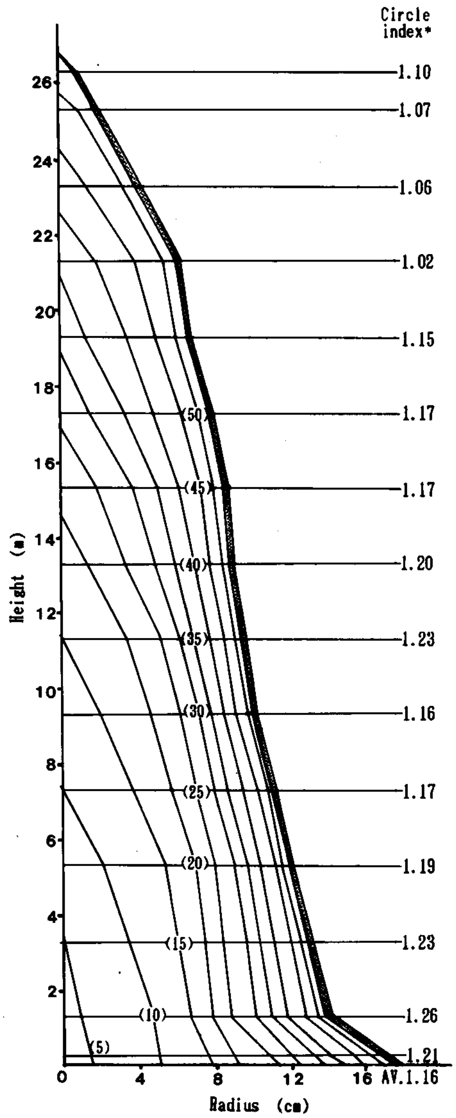

Fig. 3. Stem analysis of sugi 2.
* The proportion of the longer diameter to the shorter one on the tree-disk at different heights.

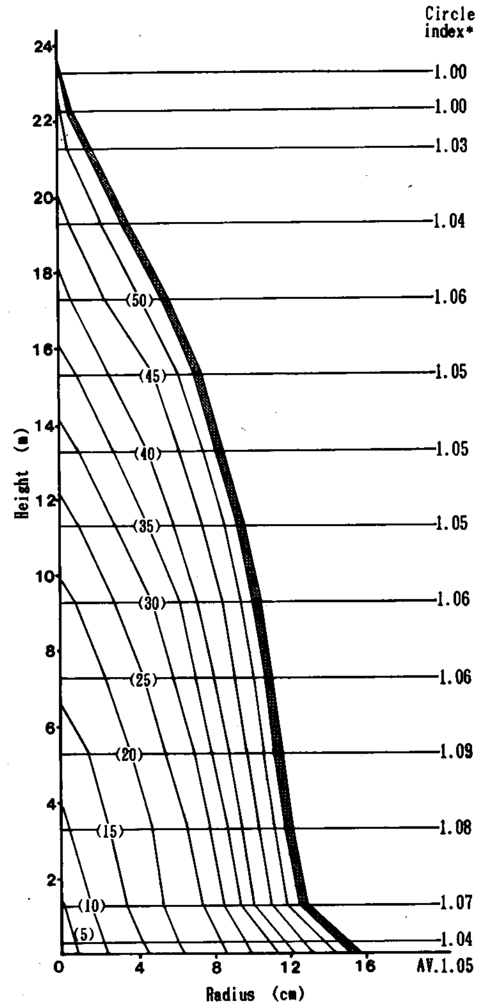

Fig. 4. Stem analysis of the hinoki.
* The proportion of the longer diameter to the shorter one on the tree-disk at different heights.

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 m^3 including the bark, and the mean increment was 0.0123, 0.0136, and 0.0109 m^3 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

Age class	Height (m)					Volume (m³)				
	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)
5	1.0	1.0	0.20	0.20	–	0.0001	0.0001	0.00002	0.00002	–
10	3.3	2.3	0.46	0.33	26.97	0.0056	0.0055	0.0011	0.0006	123.69
15	9.3	6.0	0.30	0.62	23.03	0.0287	0.0231	0.0046	0.0019	38.66
20	11.8	2.5	0.50	0.59	4.88	0.0691	0.0404	0.0081	0.0035	19.21
25	14.5	2.7	0.54	0.58	4.21	0.1209	0.0518	0.0104	0.0048	11.84
30	16.5	2.0	0.40	0.55	2.62	0.1829	0.0620	0.0124	0.0061	8.63
35	18.3	1.8	0.36	0.52	2,09	0.2477	0.0648	0.0130	0.0071	6.25
40	20.0	1.7	0.34	0.50	1.79	0.3338	0.0861	0.0172	0.0084	6.15
45	21.7	1.7	0.34	0.48	1.64	0.4652	0.1314	0.0263	0.0103	6.86
50	23.0	1.3	0.26	0.46	1.17	0.5769	0.1117	0.0223	0.0115	4.40
53	23.6	0.6	0.20	0.45	0.86	0.6538	0.0769	0.0256	0.0123	4.26
(53)						(0.7126)*				

* The figure in parenthesis is the volume including bark.

Table 6. Height and volume growths of sugi 2

Age class	Height (m)					Volume (m³)				
	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)
5	3.3	3.3	0.66	0.66	–	0.0004	0.0004	0.00008	0.00008	–
10	7.3	4.0	0.80	0.73	17.21	0.0252	0.0248	0.0050	0.0025	129.02
15	11.3	4.0	0.80	0.75	9.13	0.0862	0.0610	0.0122	0.0058	27.89
20	14.6	3.3	0.66	0.73	5.26	0.1546	0.0684	0.0137	0.0077	12.39
25	16.9	2.3	0:46	0.68	2.97	0.2286	0.0740	0.0148	0.0091	8.14
30	18.9	2.0	0.40	0.63	2.26	0.3107	0.0821	0.0164	0.0104	6.33
35	20.9	2.0	0.40	0.60	2.03	0.3841	0.0734	0.0147	0.0110	4.33
40	22.6	1.7	0.34	0.57	1.58	0.4740	0.0899	0.0180	0.0119	4.30
45	24.3	1.7	0.34	0.54	1.46	0.5855	0.1115	0.0223	0.0130	4.31
50	25.8	1.5	0.30	0.52	1.21	0.6809	0.0954	0.0191	0.0136	3.07
54	26.8	1.0	0.25	0.50	0.96	0.7356	0.0547	0.0137	0.0136	1.95
(54)						(0.7856)*				

* 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

Age class	Height (m)					Volume (m^3)				
	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)	Growth	Periodic increment	Annual increment	Mean increment	Growth rate (%)
5	1.3	1.3	0.26	0.26	--	0	0	0	0	–
10	3.8	2.5	0.50	0.38	23.92	0.0020	0.0020	0.0004	0.0002	–
15	6.5	2.7	0.54	0.43	11.33	0.0137	0.0117	0.0023	0.0009	46.94
20	9.8	3.3	0.66	0.49	8.56	0.0469	0.0332	0.0066	0.0023	27.91
25	12.1	2.3	0.46	0.48	4.31	0.1038	0.0569	0.0114	0.0042	17.22
30	14.1	2.0	0.40	0.47	3.11	0.1659	0.0621	0.0124	0.0055	9.83
35	16.1	2.0	0.40	0.46	2.69	0.2282	0.0623	0.0125	0.0065	6.58
40	18.1	2.0	0.40	0.45	2.37	0.2973	0.0691	0.0138	0.0074	5.43
45	20.1	2.0	0.40	0.45	2.12	0.3950	0.0977	0.0195	0.0088	5.85
50	22.7	2.6	0.52	0.45	2.46	0.5025	0.1075	0.0215	0.0101	4.93
53	23.8	1.1	0.37	0.45	1.59	0.5763	0.0738	0.0246	0.0109	4.67
(53)						(0.6265)*				

* The figure in parenthesis is the volume including bark.

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

(%)

Height (m)	Section of annual ring number from pith											Average of heartwood	Average of sap-wood	Average of wood*	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-				
0.3	150	165	199	192	200	133	106	149	175	174	234	163	183	175	113
1.3	167	186	185	192	183	97	162	219	205	234		168	205	190	123
3.3	132	122	136	100	84	182	196	174	200			115	188	162	108
5.3	127	73	82	82	93	144	187	170	204			91	176	148	107
7.3	136	75	72	71	90	160	174	160	193			89	172	146	103
9.3	167	181	124	81	156	158	144	180				138	160	153	106
11.3	165	174	130	71	115	165	146	180				131	164	154	103
13.3	172	159	92	120	156	136	179					136	157	152	110
15.3	167	148	95	127	149	184						137	153	150	111
17.3	167	109	140	156	180							138	159	156	119
19.3	145	118	143	167								132	155	154	142
21.3	141	129	161									–	143	143	144
22.3	171	171										–	171	171	144
23.3	170											–	170	170	145
Grand average												132	170	159	120
Min.-Max.														71-234	

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

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/m³)

Height (m)	Section of annual ring number from pith											Average	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-		
0.3	448	382	366	371	356	377	363	315	331	358	314	362	423
1.3	428	409	405	388	402	395	334	338	365	365		383	380
3.3	335	372	402	396	391	363	325	412	365			373	382
5.3	350	357	422	445	437	427	383	446	442			412	426
7.3	395	408	389	403	421	379	363	426	399			398	404
9.3	465	396	441	470	394	382	444	406				425	389
11.3	443	442	432	464	427	396	442	429				434	373
13.3	443	446	457	433	406	480	411					439	390
15.3	467	477	488	427	481	448						465	442
17.3	457	427	416	490	432							444	432
19.3	464	427	453	465								452	421
21.3	393	388	462									414	379
22.3	388	401										395	322
23.3	400											400	320
Grand average												409	392
Min.-Max												314-490	

Table 10. Distribution of annual ring width in the wood of sugi 1

(mm)

Height (m)	Section of annual ring number from pith											Average
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-	
0.3	4.0	5.5	3.3	3.1	2.4	2.2	2.3	2.7	3.4	3.5	2.6	3.2
1.3	5.1	4.2	3.1	2.3	2.0	2.3	2.7	2.9	2.4	2.4		2.9
3.3	5.1	3.4	2.7	2.4	2.2	2.1	3.0	1.9	2.4			2.8
5.3	5.7	3.6	2.5	2.3	1.8	2.1	2.7	2.0	1.8			2.7
7.3	5.0	4.5	3.1	2.3	1.8	2.1	2.6	1.8	1.5			2.7
9.3	4.8	4.0	2.9	1.9	2.0	2.4	1.8	2.1				2.7
11.3	3.7	4.7	3.3	2.0	2.1	2.7	1.7	2.3				2.8
13.3	3.6	4.0	2.9	2.6	2.8	1.9	1.8					2.8
15.3	3.2	3.4	3.1	3.3	2.2	2.0						2.9
17.3	2.3	4.0	3.6	2.4	1.8							2.8
19.3	3.0	3.4	2.5	2.8								2.9
21.3	3.0	2.5	3.1									2.9
22.3	2.3	3.4										2.9
23.3	2.0											2.0
Grand average												2.84
Min.-Max.												1.5-5.7

Table 11. Distribution of heartwood proportion in the wood of sugi 1

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

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

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

(%)

Height (m)	Section of annual ring number from pith											Average of heartwood	Average of wood	Average of wood*	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-				
0.3	162	190	190	147	124	74	191	311	343	303	283	148	286	218	156
1.3	146	151	112	86	89	134	146	219	287	230	251	117	253	188	147
5.3	154	123	70	63	89	176	240	256	217	223		100	230	168	158
7.3	125	69	53	76	186	230	241	209	207			81	215	159	164
9.3	186	101	64	73	145	217	232	226	214			106	207	166	174
11.3	111	104	63	128	236	252	222	228				93	213	170	174
13.3	145	130	95	62	184	223	209	203				108	205	170	183
15.3	142	111	76	145	208	185	185					110	181	157	156
17.3	148	112	83	176	205	187						114	189	164	175
19.3	103	57	143	195	191							80	176	157	162
21.3	55	88	171	179								72	175	154	147
23.3	104	195	185									104	190	189	161
25.3	155	201	188									—	178	178	188
26.3	239											—	239	239	189
Grand average												107	216	177	167
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 characteristicly 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 13. Distribution of basic density in the wood of sugi 2 (kg/m³)

Height (m)	Section of annual ring number from pith											Average	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-		
0.3	359	317	305	313	324	342	322	279	234	271	297	306	430
1.3	328	314	343	378	368	374	327	311	310	319	313	335	379
5.3	388	326	356	395	390	386	347	326	376	351		364	369
7.3	330	331	396	403	390	352	341	353	348			360	368
9.3	358	357	409	427	427	366	379	388	399			390	371
11.3	342	375	413	397	352	326	373	359				367	344
13.3	406	377	400	380	372	357	354	350				375	276
15.3	397	431	429	397	372	419	409					408	298
17.3	398	432	402	373	366	404						394	320
19.3	486	457	399	390	406							428	329
21.3	461	381	383	393								405	354
23.3	399	374	441									405	334
25.3	391	435										413	307
26.3	435											435	320
Grand average												371	343
Min.-Max.												234-486	

Table 14. Distribution of annual ring width in the wood of sugi 2

(mm)

Height (m)	Section of annual ring number from pith											Average
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-	
0.3	4.1	7.3	5.3	2.8	3.8	2.2	2.5	2.0	2.3	1.8	1.3	3.2
1.3	2.3	8.3	4.1	2.5	2.0	2.5	1.0	1.8	1.8	1.5	0.9	2.6
3.3	6.7	5.4	2.8	2.0	2.3	1.5	1.5	1.7	1.1	0.9		2.6
5.3	6.9	6.7	3.1	2.2	2.0	1.4	1.4	1.5	0.8	0.8		2.7
7.3	7.4	4.1	2.6	2.1	1.4	1.5	1.6	1.0	0.8			2.5
9.3	6.8	5.3	3.2	2.0	1.4	1.2	1.4	1.2	0.7			2.6
11.3	6.7	3.8	1.9	1.6	1.8	1.6	1.1	1.0				2.4
13.3	6.5	4.1	3.2	2.2	2.0	1.8	1.4	0.8				2.8
15.3	4.7	3.8	2.7	2.3	2.3	1.5	1.1					2.6
17.3	3.6	3.9	3.2	2.9	1.9	1.3						2.8
19.3	3.3	4.4	3.0	2.4	1.3							2.9
21.3	4.8	4.3	3.0	1.6								3.4
23.3	5.1	3.8	1.7									3.5
25.3	3.5	1.9										2.7
26.3	2.8											2.8
Grand average												2.75
Min.-Max.												0.7-8.3

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

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

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

Table 16. Distribution of moisture content in the wood of the hinoki (%)

Height (m)	Section of annual ring number from pith											Average of heartwood	Average of sapwood	Average of wood*	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-				
0.3	37	35	34	36	38	40	39	101	184	175	207	37	167	88	99
1.3	34	33	34	33	34	37	70	169	162	176		34	144	79	107
3.3	35	34	32	33	33	37	43	157	156	167		35	160	88	107
5.3	36	33	33	34	35	42	138	159	176			36	158	87	104
7.3	34	33	34	34	35	35	124	158	167			34	150	85	112
9.3	36	33	34	35	36	116	155	174				35	148	85	119
11.3	32	32	35	34	107	144	157					33	136	86	125
13.3	37	34	34	92	158	176						35	142	96	117
15.3	33	33	58	149	174							41	162	121	125
17.3	33	50	118	154								42	136	120	130
19.3	51	93	119									51	106	103	127
21.3	80	88										—	84	84	127
22.3	73	—										—	73	73	80
23.3	—											—	—	—	—
Grand average												36	142	92	114
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/m^3)

Height (m)	Section of annual ring number from pith											Average	Bark
	-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-		
0.3	404	433	409	404	401	400	407	392	360	380	355	395	385
1.3	440	438	426	396	394	402	384	376	384	379		402	335
3.3	462	459	457	423	441	433	423	385	405	399		429	356
5.3	483	485	417	398	424	412	390	397	385			421	347
7.3	487	479	461	408	372	381	398	394	396			420	373
9.3	533	507	455	388	385	372	378	374				424	342
11.3	571	493	447	384	383	368	362					430	334
13.3	570	495	467	385	397	395						452	382
15.3	549	536	460	425	387							471	336
17.3	594	581	491	471								534	431
19.3	540	562	537									546	409
21.3	579	550										565	480
22.3	600	—										600	470
23.3	—											—	—
Grand average												438	383
Min-Max.												355-600	

Table 18. Distribution of annual ring width in the wood of the hinoki

(mm)

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

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

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

* 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 moisure 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 438kg/m^3 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 600kg/m^3 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 B_C type (slightly dry brown forest soils). Sugi, preferring humid circumstances, is usually planted in the soils of B_E or B_F type (slightly wet or wet brown forest soils). Compared with the sugi trees in the Hiyama Experiment Forest, southern Hokkaido[9], 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[1], Toyama and Gifu[2] or Tottori Prefectures[16] 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[28]. Moreover, the 79-year-old hinoki trees planted in Otaru, Hokkaido, a very cold region, have an average height of only 17.8 m[6], 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[12].

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

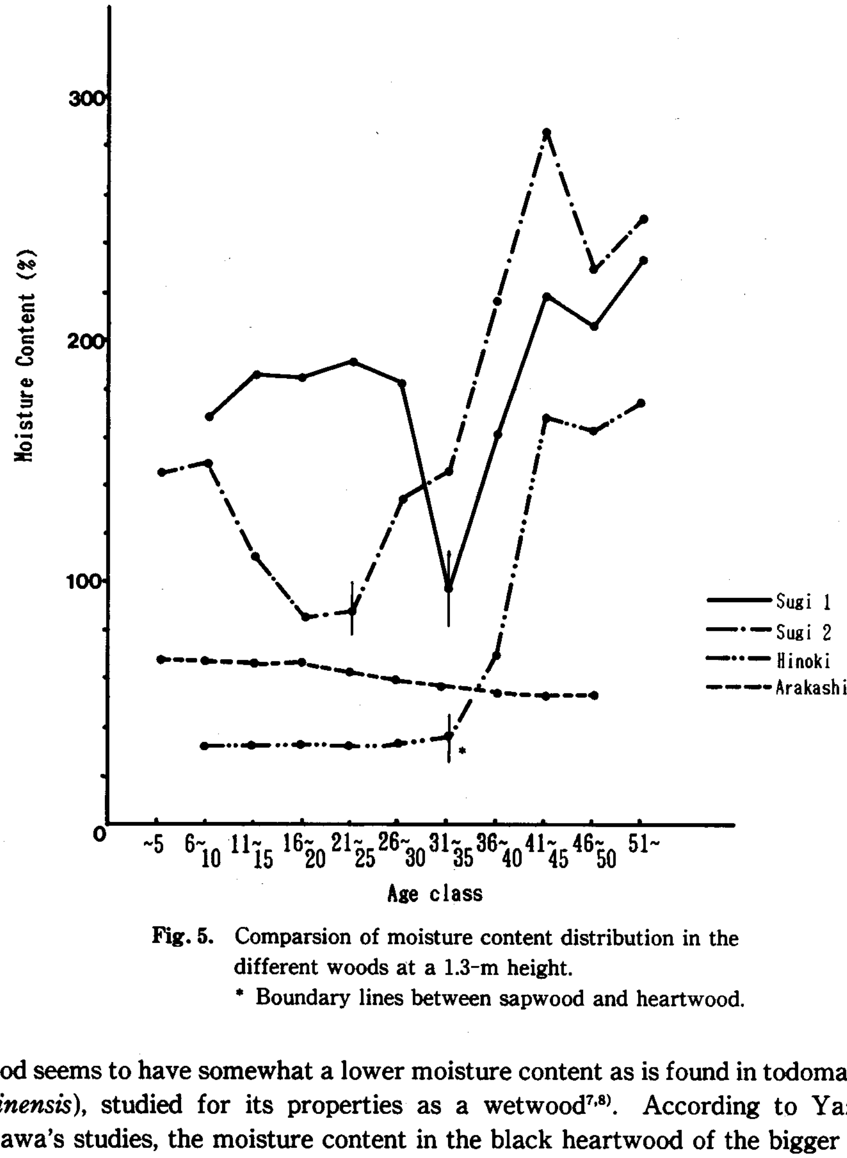

Fig. 5. Comparsion of moisture content distribution in the different woods at a 1.3-m height.
* Boundary lines between sapwood and heartwood.

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[29]. 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 moisture 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

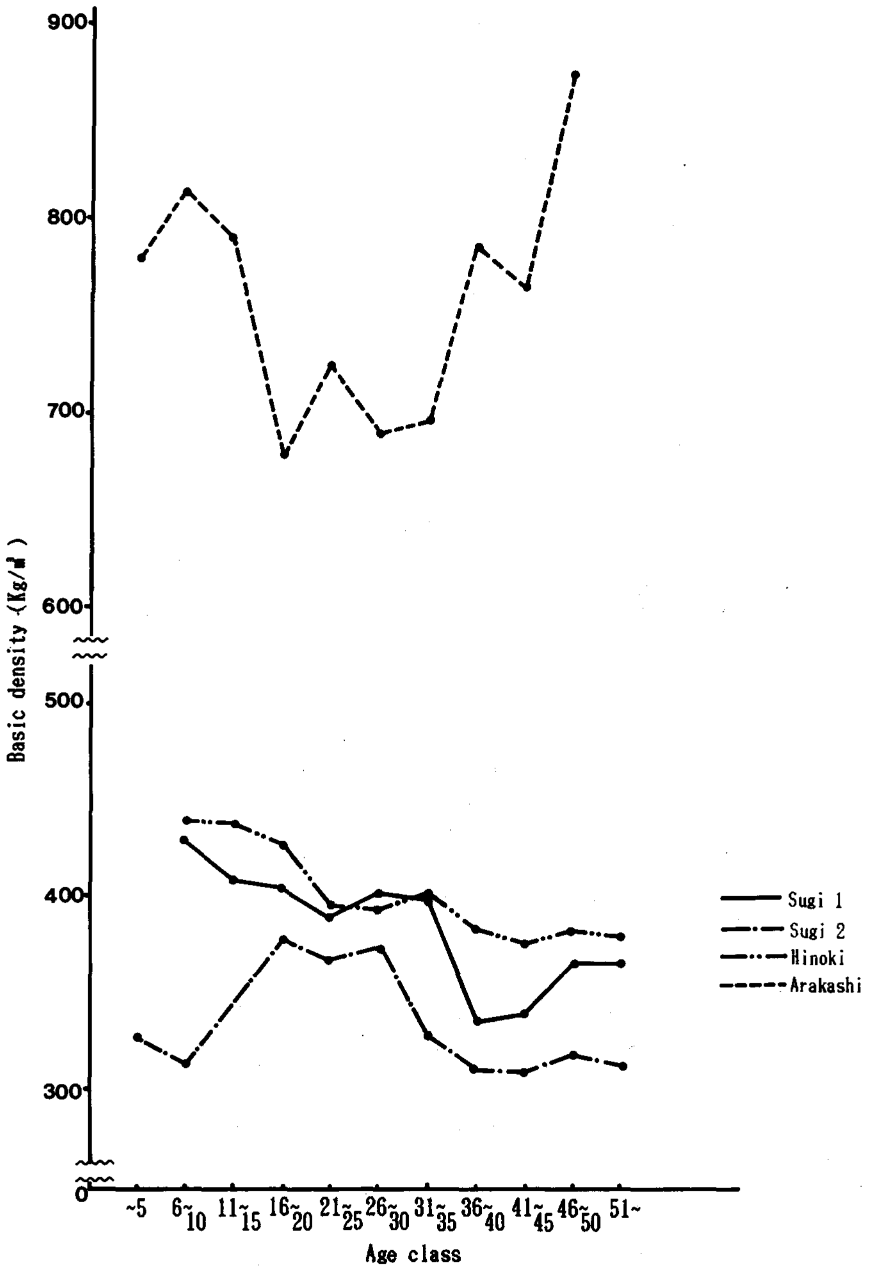

Fig. 6. Comparison of basic density distribution in the different woods at a 1.3-m height.

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[3], Chiba[4], and Tottori Prefectures[16], and considerably higher than those from the sugi trees grown at the Hiyama Experiment

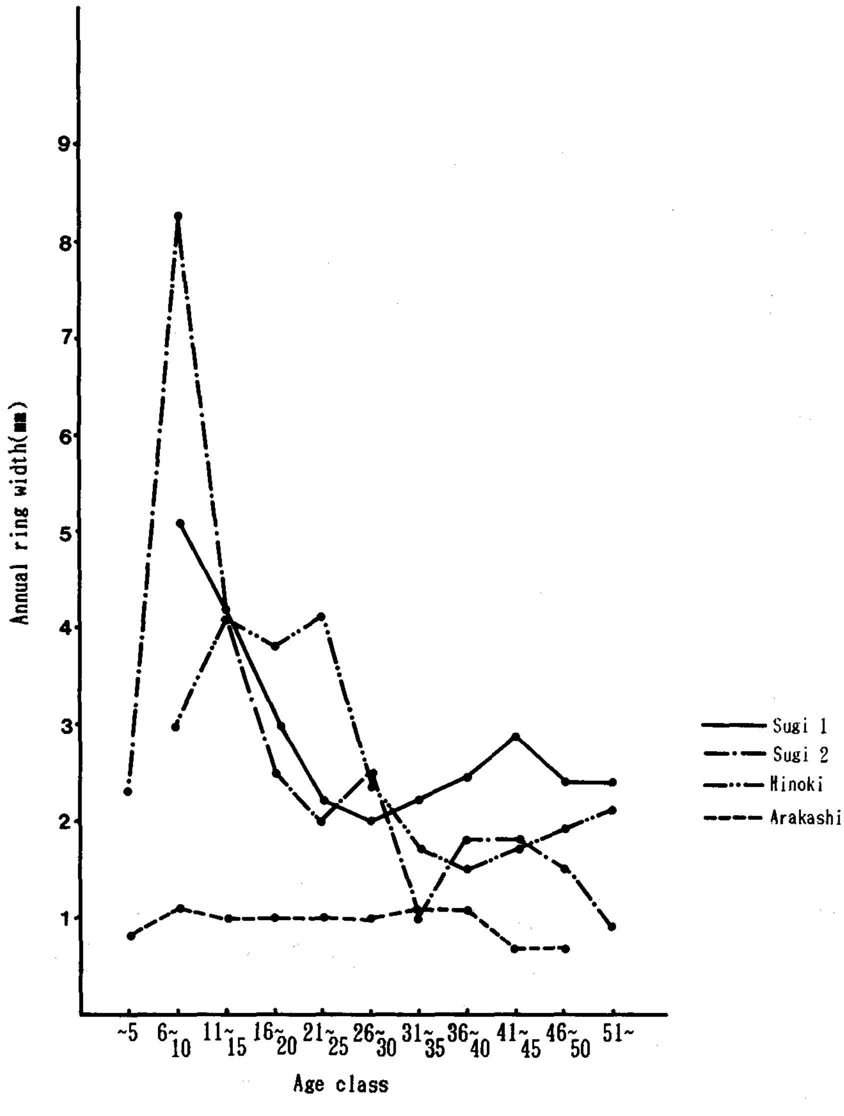

Fig. 7. Comparison of annual ring width distribution in the different woods at a 1.3-m height.

Forest.[23,25] The wood of the hinoki is also higher in its basic density than that planted in Gifu Prefecture[26,28] and Otaru[6].

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[2]. 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[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.[21] The values of MOE for hinoki trees are the highest, ranging from 100 to 160 tons/cm^2, followed by sugi trees whose values ranged from 60 to 110 tons/cm^2 in the former Experiment Forest and from 50 to 60 tons/cm^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.

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摘　　要

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430 haの森林を購入して，1925（大正14）年3月に設立された。本林は森林植物帯上暖帯北部に位置し，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°C，年降水量3,700 mm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次施業案に基づいて，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（59 ha）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ヵ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，各円板から髄を通る2本の直交する2 cm幅の細片板を作り，さらに5年輪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 m^3，平均樹高22.6 m，同胸高直径28.5 cmで，ヒノキ造林地(Plot 2)は，本数1,200本，蓄積748 m^3，平均樹高21.7 m，同胸高直径26.5 cm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 m^3，平均樹高は11.7 mで範囲は6 mから28 mにも及び，平均胸高直径は12.8 cm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*），ツブラジイ（*Shiia cuspidata*），イヌガシ（*Litsea aciculata*），ウシカバ（*Ilex sugeroki* var. *longepedunculata*），バリバリノキ（*Actinodaphne acuminata*），サカキ（*Cleyera ochnacea*），ムクロジ（*Sapindus 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B_Cタイプ，ヒノキ造林地は適潤性のB_D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520 mのところにスギ，その上部560 mの場所にヒノキが植え

られているが，500 m を超えた森林には湿性土壌（B_E，B_F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 A_0，A，B 層に分けられ，その性質を調べると，A_0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，A_0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適度の腐植とかなりの量の礫を含み，壌土質であった。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，土壌三相における固相の割合が 33—43% と高かった。しかし堅密度は硬度計で 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，適度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，アラカシは胸高直径 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 はほぼ平均木であり，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 m^3で，平均年生長量はそれぞれ 0.0123，0.0136，0.0109 m^3であった。しかしいずれも比較的初期の段階での生長が著しく，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ほぼ 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 でともに楕円形であった。

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，心材のみの平均でも 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，心材は 36%，辺材は 142% 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。このスギ心材の高含水率の原因についてはまだ十分には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心材含水率が高い傾向にある。これまでのトドマツ水食材の研究から，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くるいに注意が必要であろう。

5. 容積密度数は，スギ1と2では平均409と371 kg/m³であったのに対し，ヒノキの場合は438 kg/m³と比較的高かった。一般に材の中心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760 kg/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2.86 mm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の場合では最小の0.7 mmから最大の8.3 mm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%にもなっていた。和歌山地方演習林では，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，1.3 m高の円板の場合平均1 mm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11.3 m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21.3 m以上で心材は全く見られなかった。

8. 以上の結果から，和歌山地方演習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。