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Title	Fundamental Wood Properties of Clones Grafted with Plus-Trees of <i>Abies sachalinensis</i> (1) : Using trees thinned from the seed orchard in the Forest Tree Breeding Experimental Station, Hokkaido University
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Citation	北海道大学農学部 演習林研究報告, 51(1), 14-30
Issue Date	1994-02
Doc URL	<a href="https://hdl.handle.net/2115/21376">https://hdl.handle.net/2115/21376</a>
Type	departmental bulletin paper
File Information	51(1)_P14-30.pdf



## Fundamental Wood Properties of Clones Grafted with Plus-Trees of *Abies sachalinensis* (I)

— Using trees thinned from the seed orchard in the Forest Tree  
Breeding Experimental Station, Hokkaido University —\*

by

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種々のトドマツ精英樹からつぎ木されたクローンの基礎材質 (I)

— 北大林木育種試験場採種園の間伐木を用いて —\*

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### Abstract

The fundamental properties for wood quality such as basic density, annual ring width, and moisture content were examined, together with YOUNG's modulus in the bending of standing trees. The specimens used were 226 grafted trees of *Abies sachalinensis*, consisting of 46 clones row-thinned from the seed orchard in the Forest Tree Breeding Experimental Station, Hokkaido University. The results obtained were statistically investigated. The averages of basic density, annual ring width, moisture content in heartwood, and YOUNG's modulus were 342 kg/m<sup>3</sup>, 3.9 mm, 141.2 %, and 86.0 tons/cm<sup>2</sup>, respectively. The analyses of variances of these properties showed significant differences among clones. The repeatabilities, heritabilities as a broad sense, of the properties were generally low, as reflected in 0.13 for YOUNG's modulus to 0.46 for basic density. Correlations between two factors in the properties were also low, the coefficients of which, however, were statistically significant between basic densities and diameters at breast height or annual ring widths, and between moisture contents in heartwood and basic densities of heartwood or annual ring widths of heartwood, and not significant between YOUNG's moduli and basic densities or annual ring widths.

**Key words :** Forest Tree Breeding Experimental Station, *Abies sachalinensis*, Clone, Wood quality, YOUNG's modulus

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\*Received September 30, 1993. 1993年9月30日受理

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### I. Introduction

According to "A Guide for Forest Tree Breeding Projects"<sup>1,2)</sup> decided by the Forestry Agency of the Japanese Government in 1956, a new large-scale tree breeding program was started with the selection of plus-trees, followed by propagation using graftings or cuttings and development of seed orchards. In the Forest Tree Breeding Experimental Station of Hokkaido University, a number of plus-trees of *Abies sachalinensis* MAST. (Sakhalin fir, Japanese name ; todomatsu), one of the most popular species in Hokkaido, were selected in 1967 from natural forests mainly in the University Forests. After the scions were grafted and the resultant saplings were cultivated in a nursery for several years, they were then planted in a seed orchard in 1971<sup>4)</sup>. We can expect a large quantity of excellent seeds to be produced from the orchard in the near future.

The wood of *A. sachalinensis* is soft, creamy-white in color, and light in weight, and is used extensively in house construction, and the waste for pulp. However, the wood often is too light and too wide in annual ring width to be used in structural timber. Furthermore, the tree often has an extremely high moisture content in heartwood called wetwood, which can cause the tree to crack in winter, and deteriorate (split, collapse, stain, etc.) when it is dried.

We have previously investigated the wood quality of *A. sachalinensis* clones obtained from national seed orchards<sup>6,7,12)</sup>. In this study, using *A. sachalinensis* clones thinned from the seed orchard of the Forest Tree Breeding Experimental Station, such fundamental physical properties of the wood as basic density, annual ring width, moisture content were examined, including the measurement of YOUNG's modulus in the bending of standing trees. We also examined the results statistically by analyses of variances, repeatabilities, heritabilities as a broad sense, and correlations. Even though the specimens used in this study were too young to be used in house construction, and the management of the seed orchard was carried out more carefully than usual plantations, the results in this study based on genetics and statistics are believed to be very useful.

Studies on the estimation and cultivation of wood of high quality have been reported by the Forestry Department of Hokkaido Prefecture<sup>2)</sup>, Forestry Agency<sup>1)</sup>, and the Institute for Technical Development of Forestry<sup>5)</sup>. The YOUNG's modulus, also known as the modulus of elasticity (MOE), is a measure of stiffness or rigidity and is said to be the best indicator of wood strength using a non-destructive method. Since 1991 it has been decided by the Japanese Agricultural Standard (JAS) that the YOUNG's modulus in bending is measured for structural timber<sup>13)</sup>. Strength tests are usually conducted in a laboratory with small, clear specimens of air-dried wood. However, this method developed by KOIZUMI *et al.* can be easily carried out on a standing tree in a forest<sup>8,9,10,14)</sup>. The results of their tests agreed with the results of laboratory tests on logs obtained from the same trees, and the values were proportional to those of small specimens<sup>8)</sup>.

We thank Mr. S. HAYASHI, Ex-technical official, for his help in the measurements, and also the members of the Forest Tree Breeding Experimental Station for their managerial efforts of the seed orchard. This study was supported in part by a Grand-in-Aid for Scientific Research from the Japanese Ministry of Education (No. 05660151).

## II. Outline of the Seed Orchard<sup>4)</sup>

The seed orchard (Photo 1) from which the specimens for this study were collected, is in the Forest Tree Breeding Experimental Station of Hokkaido University. The Experimental Station was started in 1965 with the purchase of a 20-ha wild field. The location is in the outskirts of Nayoro City in the center of the Nayoro Basin, northern Hokkaido. It lies at 142°25' east longitude and 44°30' north latitude. The mean annual temperature is 5.1 °C. Due to the location of the basin, it has an inland climate with a wide range in temperature. A recent ten year survey shows a maximum temperature in summer of 34.5 °C and a minimum temperature in winter of -35.7 °C. There is also often a heavy frost as late as June. The yearly precipitation is around 1,000 mm, mainly falling as snow which



**Photo 1.** The seed orchard of *A. sachalinensis* in the Forest Tree Breeding Experimental Station.



**Photo 2.** The seed orchard of *A. sachalinensis* after row thinning.

covers the ground at a maximum depth of 150 cm in winter. The soils are composed of thick peat<sup>15)</sup>, which meant soil amendment had to be carried out by soil dressing with river sand and culvert-drainage before cultivation of nursery stocks.

In order to produce good seeds and supply their seedlings for plantation, the selection process of plus-trees of *Abies sachalinensis* and *Picea glehnii* was carried out in natural forests of the University Forests from 1967. The standard of selection was based on apparent qualities, phenotypes, such as tree height over 20 m, DBH over 30 cm, no decay and defects, straightness of stem, full bole, and power of growth compared with neighboring trees<sup>11)</sup>. The scions collected were grafted and cultivated in the nursery over several years. In 1971, a 1-ha seed orchard for *A. sachalinensis* was made by planting 1,600 of the resultant saplings in an arrangement consisting of 49-types of 7×7. Fertilizers and agricultural chemicals have been occasionally added, and a few cones have fruited. In April 1993, row-thinning was first carried out, as shown in Photo 2, according to the programs.

### III. Materials and Experiments

#### 1. Materials

Specimens were 46 clones of *A. sachalinensis* totaling 226 trees, which were selected at random by five ramets per clone from the planted lines thinned in April 1993.

The clones were as follows : 1001, 1004, and 1007 derived from the Teshio Experimental Forest (Toikanbetsu), 2001, 2002, 2003, 2004, 2008, 2009, 2010, 2011, 2012, 2013, 2015, 2016, 2018, 2020, 2022, 2023, 2025, 2026, 2027, 2028, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, and 2043 from the Nakagawa Experimental Forest (Otoineppu and Nakagawa), 3001 and 3002 from the Uryu Experimental Forest (Moshiri). Also, Teshio 101C and 103C, Haboro 112C, Nayoro 101B, Shimokawa 127C and 130C, Asahi 101B and 102B were derived from respective national district forest offices. They are shown in Fig. 1 and Table 1.

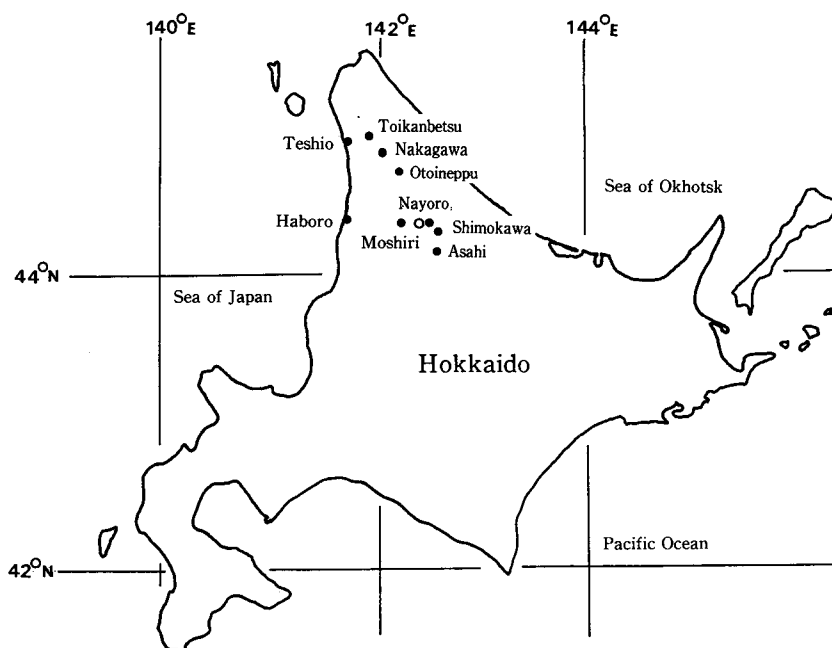


Fig. 1. Location of the seed orchard (○) and locations of the plus-trees selected for cultivation of clones (●).

## 2. Experiments

Prior to row-thinning, the measurements of YOUNG's modulus in bending were carried out on standing trees, after tree heights and diameters at breast height were measured. As shown in Fig. 2, the instrument developed for measuring was made up a 120-cm long lever arm and a middle-ordinate deflection sensor placed between two 1-m long boards, and it was attached to the trunk pruned to a height of 2 m. The trunk was bent by loading weights of 3, 6, or 13 kg at the end of the lever arm set at 180 cm above ground so as to obtain bending stress of about 10 kg/cm<sup>2</sup>, and the deflection was detected by the sensor with a transformer (adjustable from 0.001 to 5 mm) fixed on the trunk at 120 cm above ground on the side opposite to the lever arm. The deflection produced was shown on a digital gauge induced by the sensor. To minimize the error involved, the measurements were made in two loading directions, right angle to each other, and averaged. The radius was calculated by measuring the circumference at the 180 and 120 cm heights. The bark thickness was determined by inserting a scale-marked driver.

The YOUNG's modulus in bending ( $E$ ) for this experiment is given by following equation<sup>8)</sup>:

$$E = s^2 M / 2\pi\delta(r_{120} - t_b)^4$$

Where  $s$  is the span of the sensor apparatus;  $M$  is the bending moment calculated by multiplying the weight by the arm length plus the radius of the trunk at 180 cm height;  $r_{120}$  is the radius at the 120 cm height;  $t_b$  is the bark thickness, and  $\delta$  is the deflection produced<sup>8)</sup>.

Immediately after thinning, two disks of 5-cm thickness were cut near breast height

Table 1. Tree heights and diameters at breast height by clones of *A. sachalinensis*

Clone names	Number of ramets	Tree heights				Diameters at breast height			
		Ranges (m)	Aver ages	S.D. (cm)	C.V. (%)	Ranges (cm)	Aver ages	S.D. (cm)	C.V. (%)
1001	5	8.3~9.0	8.5	0.30	4	12.8~14.0	13.2	0.50	4
4	4	4.6~8.9	6.9	1.86	27	8.4~16.0	11.7	3.55	30
7	5	5.4~6.7	5.9	0.50	8	10.6~13.0	11.7	0.99	8
2001	5	5.5~7.9	6.4	1.02	16	8.4~14.0	11.5	2.28	20
2	5	5.6~8.0	6.8	1.00	15	11.8~19.6	16.6	2.91	18
3	4	5.2~8.3	6.7	1.51	23	8.5~15.0	10.9	2.84	26
4	5	6.3~8.0	7.0	0.63	9	11.6~13.0	12.3	0.61	5
8	5	5.8~8.2	7.2	0.94	13	10.0~16.8	13.7	2.69	20
9	4	5.4~7.6	6.3	1.01	16	11.0~15.4	13.5	1.84	14
10	5	6.8~9.0	8.0	0.83	10	10.8~18.8	15.2	3.25	21
11	5	4.7~7.6	6.5	1.19	18	9.4~16.5	12.9	2.85	22
12	5	3.9~7.7	6.2	1.52	25	8.5~12.8	10.7	2.13	20
13	4	5.4~7.8	6.2	1.11	18	9.6~14.4	11.4	2.18	19
15	5	5.9~7.7	7.1	0.70	10	8.4~16.5	12.2	3.03	25
16	5	5.4~7.9	6.5	0.96	15	10.5~15.0	13.4	1.89	14
18	5	5.9~7.9	7.1	0.78	11	14.0~19.1	16.1	1.99	12
20	5	7.1~8.8	7.9	0.70	9	13.0~19.5	16.1	3.15	20
22	5	6.2~8.3	7.1	0.86	12	10.5~14.8	12.6	1.53	12
23	5	6.1~7.5	6.7	0.66	10	11.5~14.4	13.1	1.19	9
25	5	5.8~7.1	6.3	0.51	8	8.5~15.4	11.3	2.91	26
26	5	5.5~8.1	7.1	1.03	15	11.2~19.4	15.1	2.92	19
27	5	4.6~8.3	6.0	1.45	24	9.0~14.8	11.8	2.13	18
28	5	4.4~8.2	7.2	1.58	22	8.8~14.6	12.6	2.24	18
30	5	6.3~7.8	6.8	0.58	9	11.9~16.5	15.1	1.85	12
31	5	5.2~9.0	7.0	1.63	23	12.8~20.4	17.7	3.04	17
32	5	5.8~9.1	7.5	1.17	16	12.0~20.4	16.6	3.34	20
33	5	5.8~7.4	6.4	0.59	9	7.0~14.3	9.9	2.72	27
34	5	6.7~7.3	7.0	0.26	4	15.0~17.2	16.0	0.86	5
35	5	7.1~8.4	7.9	0.49	6	12.0~16.6	14.7	1.79	12
36	5	6.5~8.0	7.5	0.64	9	15.0~17.6	16.4	1.04	6
37	5	6.7~8.6	7.3	0.78	11	11.2~16.8	13.8	2.06	15
38	5	6.5~8.2	7.2	0.62	9	10.6~13.0	12.2	0.94	8
39	5	4.0~7.4	6.2	1.42	23	6.1~16.0	11.9	3.97	33
40	5	6.8~8.4	7.5	0.66	9	12.0~17.2	14.4	2.42	17
41	5	6.1~8.8	7.7	1.00	13	12.1~15.4	13.8	1.18	9
43	5	5.5~7.4	6.4	0.68	11	9.8~15.6	12.3	2.60	21
3001	5	7.8~9.1	8.4	0.52	6	12.0~17.5	14.6	2.44	17
2	5	5.9~8.4	7.2	1.00	14	10.4~14.6	12.9	1.55	12
T.101C	5	5.4~7.6	6.8	0.84	13	7.2~13.5	11.1	2.82	25
103C	5	5.8~8.1	6.9	1.10	16	10.5~16.0	13.4	2.24	17
H.112C	5	3.5~7.0	5.1	1.25	25	7.5~11.6	10.0	1.75	18
N.101B	5	6.6~8.0	7.3	0.63	9	10.1~14.8	13.0	1.81	14
S.127C	5	5.7~6.6	6.2	0.36	6	8.2~12.4	10.7	1.70	16
130C	5	6.2~9.0	7.9	1.16	15	10.0~17.5	14.0	3.26	23
A.101B	5	5.4~7.1	6.1	0.76	12	8.2~16.0	12.4	3.47	28
102B	5	4.5~8.4	6.6	1.47	22	7.5~16.6	13.1	3.42	26
Totals (Averages)	226	3.5~9.1	6.9	1.11	16	6.12~20.4	13.3	2.86	22

Notes : S.D. ; Standard deviations. C.V. ; Coefficients of variations.

Clone names of the 1,000, 2,000 and 3,000 levels mean clones grafted with the plus-trees selected from natural forests of the Teshio(Toikanbetsu), Nakagawa(Nakagawa, Otoineppu), and Uryu(Moshiri) Experimental Forests, Hokkaido Univ., respectively. The names of T, H, N, S, and A mean clones grafted with plus-trees selected from natural forests of the Teshio, Haboro, Nayoro, Shimokawa, and Asahi national district forest offices in Forestry Agency.

of the trunk from each specimen, and the boundary between heartwood and sapwood was marked. In the laboratory the green disks were cut into parallelepipeds of 3-cm width having pith, and then they were divided into parts of heartwood and sapwood, which were used to measure basic density ( $\text{kg}/\text{m}^3$ : dry weight-green volume basis) and average annual ring width (mm), as well as to determine moisture content (%: dry weight basis) according to previous reports<sup>7,12)</sup>. In this experiment, knots, compression wood and other defects were avoided.

Clonal differences of these wood properties were examined by the analysis of variance, and their repeatabilities ( $r^2$ ) were estimated by following equation<sup>7,12)</sup>:

$$r^2 = \sigma_c^2 / \sigma_c^2 + \sigma_E^2$$

where  $\sigma_c^2$  is the clone variance and  $\sigma_E^2$  is the environment variance. Furthermore, the correlations between two factors in these properties were calculated.

#### IV. Results and Discussion

##### 1. Tree heights and diameters at breast height

Table 1 shows the tree heights and diameters at breast height for the different clones. The average height was 6.9 m, 22 years after plantation. The maximum was 8.5 m for Clone 1001, and the minimum was 5.1 m for Haboro 112C. Tree heights ranged from 3.5 m obtained from a ramet of Haboro 112C to 9.1 m obtained from two respective ramets of 2032 and 3001, having a coefficient of variation of 16 %. The average diameter at breast height was 13.3 cm. The maximum among clones was 17.7 cm for 2031, and the minimum was 9.9 cm for 2033. The total range was from 6.1 cm obtained from a ramet of 2039 to 20.4 cm obtained from two respective ramets of 2031 and 2032, having a coefficient of variation of 22 %.

##### 2. Properties for wood quality

The properties for wood quality by clones are shown in Table 2.

The average basic density of heartwood and sapwood were  $342 \text{ kg}/\text{m}^3$  and  $346 \text{ kg}/\text{m}^3$ , respectively. The coefficients of variation were as small as 8 % and 10 %, respectively. The average of the basic density calculated by the weighted average of those of heartwood and sapwood, the whole basic density, showed  $342 \text{ kg}/\text{m}^3$ , equal to the value of heartwood. The maximum of the whole basic density was  $403 \text{ kg}/\text{m}^3$  for Clone 2033, and the minimum was  $303 \text{ kg}/\text{m}^3$  for 2002. The total range was from  $276 \text{ kg}/\text{m}^3$  obtained from a ramet of 2002, which had the second largest average diameter of 16.6 cm among clones, to  $427 \text{ kg}/\text{m}^3$  obtained from a ramet of Clone 2033, which had the smallest average diameter of 9.9 cm. Basic density of wood seems to be inversely proportional to the diameter of trees. The basic densities obtained from these clones were relatively high, in comparison with that the average from clones of the Shiokari seed orchard similarly derived from natural forests in northern Hokkaido, was  $302 \text{ kg}/\text{m}^3$ <sup>12)</sup>. Also MIYAJIMA reported that the average basic

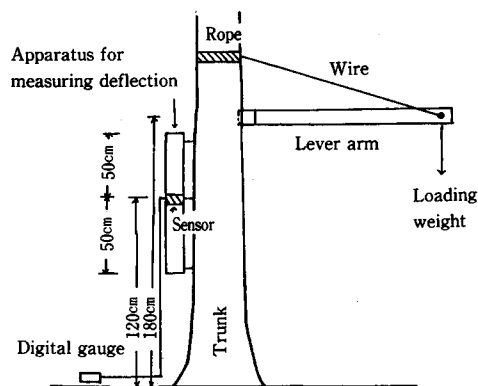


Fig. 2. A schematic diagram of the apparatus for the measurement of YOUNG'S modulus in bending.

densities of planted *A. sachalinensis* measured in various locations were 335 kg/m<sup>3</sup> for 28 samples collected from Eniwa, 325 kg/m<sup>3</sup> for 43 samples from Atsuga, 283 kg/m<sup>3</sup> for 23 samples from Shiraoui, and 313 kg/m<sup>3</sup> for 71 samples from Kami-ashibetsu<sup>3)</sup>. However, the specific gravity calculated from 342 kg/m<sup>3</sup> of the average basic density became 0.415 at 15 % moisture content<sup>6)</sup>. The value is slightly less than the minimum specific gravity of 0.43 required for higher structural timber grades of *A. sachalinensis* according to JAS<sup>7)</sup>.

The average annual ring widths for both heartwood and sapwood were the same at 3.9 mm. Their coefficients of variation were high at 19 % and 22 %, respectively. The average of the whole annual ring width calculated by the weighted average was also 3.9 mm. The maximum of the whole width was 4.7 mm for Clones 2002 and 2036, and the minimum was 2.7 mm for 2033. The range was from 2.4 mm obtained from two respective ramets of 2013 and Asahi 102B to 5.6 mm obtained from a ramet of 2002, having a coefficient of variation of 19 %, the same as that of heartwood. Generally, the average annual ring widths from these clones were narrow for the clones of the plus-trees, because the average from the clones of the Shiokari seed orchard was 4.9 mm, though fertilizers had been given to these clones every year<sup>12)</sup>. However, compared with MIYAJIMA's study in which the averages were 3.1 mm for samples from Eniwa, 3.6 mm from Atsuga, 5.0 mm from Shiraoui, and 3.9 mm from Kami-ashibetsu<sup>3)</sup>, the average of 3.8 mm in our study was moderate. As the maximum annual ring width required for higher structural timber grades is 6.0 mm, all the clones were within this standard.

The average moisture content in heartwood was high at 141.2 %. The maximum was 192.2 % for Clone 1001, and the minimum was 92.0 % for 2032. The range was from 63 % obtained from a ramet of 2032 to 224 % from a ramet of 1001, and the coefficient of variation was high at 24 %. Although the definition of wetwood is not yet clear, if the wetwood is defined as wood which has more than 100 % of the moisture content in the heartwood, these clones are almost all wetwoods. This seems to be caused mainly by the soil condition, as the clones of the plus-trees selected from similar forests and planted in the Shiokari seed orchard had an average moisture content in heartwood of 96.2 %, though including a few clones of wetwoods<sup>12)</sup>. The average moisture content in sapwood was 189.1 %. The maximum content was 236.2 % for Clone 2002 which had the widest whole annual ring width of 4.7 mm, and the minimum was 160.6 % for 3001. The range was from 131 % obtained from a ramet of 2037 to 252 % from a ramet of 2002, with a low coefficient of variation of 13 %. Compared to the average moisture content in sapwood of the clones from the Shiokari seed orchard which was 212.4 %<sup>12)</sup>, it was generally low.

The average YOUNG's modulus in bending was 86.0 tons/cm<sup>2</sup>. The maximum was 112.9 tons/cm<sup>2</sup> for Clone 2011, and the minimum was 65.7 tons/cm<sup>2</sup> for 2025. The range was from 45.4 tons/cm<sup>2</sup> obtained from a ramet of 2036 to 136.3 tons/cm<sup>2</sup> obtained from a ramet of 2037, with a coefficient of variation of 22 %. Compared with the study by KOIZUMI et al. which showed 110.3 tons/cm<sup>2</sup> and 114.3 tons/cm<sup>2</sup> for YOUNG's modulus carried out by the same method on standing trees of *A. sachalinensis* planted in the Hiyama Experimental Forest<sup>10)</sup>, the value of 86.0 tons/cm<sup>2</sup> was relatively low, but belongs to E90 (80 tons/cm<sup>2</sup>-100 tons/cm<sup>2</sup>) of the middle class among 6 grades for structural timber according to JAS<sup>13)</sup>. Compared with our previous study in which an average of 50.13 tons/cm<sup>2</sup> was obtained using 98 trees of *Cryptomeria japonica* planted in the Hiyama Experimental Forest<sup>14)</sup>, this value was considerably high.

Table 2. Some properties for wood quality of clones of *A. sachalinensis*

Clone names	Number of ramets	Basic densities of heartwood				Basic densities of sapwood				Basic densities				Average annual ring widths of heartwood			
		Ranges kg/m <sup>3</sup>	Av. kg/m <sup>3</sup>	S.D. kg/m <sup>3</sup>	C.V. %	Ranges kg/m <sup>3</sup>	Av. kg/m <sup>3</sup>	S.D. kg/m <sup>3</sup>	C.V. %	Ranges kg/m <sup>3</sup>	Av. kg/m <sup>3</sup>	S.D. kg/m <sup>3</sup>	C.V. %	Ranges mm	Av. mm	S.D. mm	C.V. %
1001	5	306~317	312	5.26	2	293~382	328	33.19	10	309~329	317	7.95	3	3.1~4.0	3.6	0.36	10
4	4	329~378	351	22.04	6	306~402	349	41.71	12	320~368	350	21.38	6	2.4~4.9	3.6	1.28	36
7	5	352~422	378	26.14	7	364~399	384	15.34	4	357~416	380	22.08	6	3.0~4.3	3.8	0.47	12
2001	5	310~421	344	45.06	13	303~383	331	31.85	10	308~391	340	34.37	10	2.4~4.4	3.3	0.77	23
2	5	275~332	299	23.39	8	278~331	310	20.11	6	276~332	303	21.54	7	3.6~6.4	4.7	1.03	22
3	4	353~390	368	15.90	4	312~392	347	33.52	10	340~390	356	23.04	6	2.2~3.2	2.7	0.41	15
4	5	345~367	360	8.79	2	328~380	345	21.60	6	338~366	353	10.03	3	2.5~3.2	2.8	0.27	10
8	5	332~367	352	15.42	4	298~369	332	31.37	9	322~362	345	15.65	5	3.4~4.2	3.9	0.30	8
9	4	304~323	315	8.10	3	278~351	322	33.00	10	297~330	316	13.94	4	3.6~4.2	3.8	0.27	7
10	5	308~359	333	23.93	7	286~374	333	32.75	10	307~364	333	24.93	7	3.7~5.1	4.5	0.54	12
11	5	324~418	363	34.59	10	334~394	371	22.64	6	327~413	365	31.15	9	2.8~4.6	3.8	0.86	23
12	5	318~383	352	25.86	7	348~419	383	34.14	9	335~395	362	26.70	7	2.2~3.8	3.1	0.60	19
13	4	323~360	336	16.50	5	315~388	341	32.71	10	326~353	337	12.69	4	2.6~4.4	3.7	0.84	23
15	5	297~358	326	28.36	9	291~459	347	69.07	20	295~374	329	32.33	10	3.1~4.2	3.7	0.44	12
16	5	335~355	347	7.69	2	318~360	332	16.80	5	330~351	341	7.70	2	3.3~4.2	3.8	0.41	11
18	5	315~349	328	13.74	4	314~359	335	16.26	5	315~345	331	12.97	4	4.0~5.3	4.6	0.63	14
20	5	335~377	349	16.58	5	330~402	364	29.65	8	335~378	352	16.05	5	3.7~5.1	4.3	0.59	14
22	5	345~401	370	23.53	6	321~403	359	32.74	9	355~402	367	22.86	6	3.1~4.4	3.9	0.51	13
23	5	313~343	333	11.84	4	290~393	333	38.55	12	321~340	332	6.88	2	3.2~3.9	3.6	0.26	7
25	5	324~346	334	9.28	3	308~383	348	31.75	9	319~355	338	13.63	4	3.0~4.1	3.4	0.43	13
26	5	332~412	370	34.59	9	335~410	360	32.18	9	333~412	367	33.65	9	2.7~4.0	3.9	0.85	22
27	5	350~385	366	15.18	4	341~414	370	27.05	7	354~392	367	14.82	4	2.7~3.5	3.1	0.30	10
28	5	304~409	347	41.58	12	313~358	333	21.41	6	310~392	343	33.87	10	2.7~4.9	3.9	0.82	21
30	5	312~364	326	21.73	7	303~349	324	16.76	5	309~354	325	17.48	5	3.7~4.9	4.3	0.43	10
31	5	317~419	362	39.80	11	324~367	346	19.49	6	320~405	359	34.14	10	3.3~5.5	4.3	0.85	20
32	5	321~348	333	10.55	3	300~356	329	26.20	8	318~338	331	7.92	2	3.6~6.0	4.4	0.93	21
33	5	381~425	405	17.73	4	381~432	402	21.94	5	381~427	403	17.98	4	2.4~3.3	2.8	0.37	13
34	5	324~351	338	10.83	3	329~364	343	14.39	4	327~343	339	6.99	2	4.0~4.7	4.5	0.30	7
35	5	336~365	347	10.77	3	317~365	340	19.94	6	331~357	344	11.30	3	3.2~3.9	3.7	0.27	7
36	5	336~355	344	10.41	3	350~407	376	24.05	6	340~367	352	13.01	4	4.3~4.9	4.6	0.26	6
37	5	331~362	348	12.75	4	309~343	331	13.10	4	336~351	343	5.97	2	3.2~4.5	3.9	0.50	13
38	5	298~339	316	16.77	5	291~372	324	33.95	10	302~341	316	16.23	5	3.1~4.5	3.7	0.58	15
39	5	334~368	349	15.96	5	301~341	324	15.57	5	326~354	339	11.78	3	2.9~4.2	3.6	0.52	15
40	5	300~336	317	16.36	5	305~360	330	22.93	7	302~342	322	18.19	6	3.3~5.1	4.3	0.67	15
41	5	326~367	348	18.90	5	282~358	313	27.70	9	313~363	337	19.98	6	4.0~5.4	4.6	0.51	11
43	5	344~370	359	11.14	3	319~376	344	25.44	7	337~372	352	16.38	5	3.0~4.8	3.9	0.66	17
3001	5	330~368	346	13.85	4	370~425	394	21.50	5	354~368	361	6.72	2	3.3~5.2	4.3	0.71	17
2	5	310~359	338	20.95	6	345~431	373	34.54	9	323~361	345	14.37	4	3.3~4.5	4.1	0.49	12
T.101C	5	319~364	346	18.12	5	341~410	367	26.16	7	325~376	353	19.32	5	2.5~4.4	3.5	0.68	20
103C	5	297~333	315	14.12	4	292~338	314	21.67	7	295~335	315	15.22	5	3.5~4.7	4.1	0.45	11
H.112C	5	300~343	329	19.07	6	327~390	354	27.59	8	331~346	337	6.22	2	2.9~4.3	3.5	0.67	19
N.101B	5	297~363	331	23.51	7	306~407	365	44.90	12	300~353	340	22.97	7	3.5~5.1	4.0	0.64	16
S.127C	5	323~341	334	6.86	2	314~357	342	18.88	6	327~346	336	7.77	2	3.3~4.2	3.6	0.37	10
130C	5	339~371	354	15.09	4	341~358	348	7.50	2	340~367	352	11.95	3	3.4~5.0	4.4	0.64	15
A.101B	5	293~319	310	9.90	3	292~378	339	37.59	11	297~332	319	15.12	5	2.8~5.5	4.0	1.07	27
102B	5	289~311	301	7.92	3	287~342	321	24.45	8	288~319	308	13.08	4	2.3~4.5	3.8	0.87	23
Totals (Averages)	226	275~425	342	27.74	8	278~459	346	33.58	10	276~427	342	25.71	8	2.2~6.4	3.9	0.74	19

Notes : Av. ; Averages, S.D. ; Standard deviations, C.V. ; Coefficients of variations.

Average annual ring widths of sapwood				Average annual ring widths				Moisture contents in heartwood				Moisture contents in sapwood				YOUNG'S moduli in bending			
Ranges	Av.	S.D.	C.V.	Ranges	Av.	S.D.	C.V.	Ranges	Av.	S.D.	C.V.	Ranges	Av.	S.D.	C.V.	Ranges	Av.	S.D.	C.V.
mm	mm	mm	%	mm	mm	mm	%	%	%	%	%	%	%	%	%	t/cm <sup>2</sup>	t/cm <sup>2</sup>	t/cm <sup>2</sup>	%
3.0~4.5	3.8	0.62	16	3.4~4.1	3.7	0.31	8	163~224	192.2	26.64	14	165~211	196.6	19.82	10	76.2~101.2	90.1	10.73	12
2.9~5.5	4.1	1.17	29	2.7~5.1	3.7	1.24	33	111~181	134.0	32.42	24	179~204	193.7	11.61	6	52.7~80.5	70.2	12.68	18
2.9~3.5	3.2	0.26	8	3.2~4.0	3.6	0.28	8	92~141	115.0	21.76	19	139~183	163.0	18.93	12	64.5~102.7	89.2	15.25	17
2.4~4.1	3.3	0.78	24	2.5~4.3	3.3	0.66	20	130~204	156.8	30.16	19	159~198	181.8	16.65	9	60.4~120.0	86.8	22.47	26
4.3~5.2	4.6	0.35	8	3.8~5.6	4.7	0.64	14	113~154	138.2	16.84	12	210~252	236.2	19.70	8	72.7~87.4	81.2	5.47	7
3.2~3.8	3.5	0.24	7	2.6~3.4	3.0	0.33	11	107~142	125.7	14.38	11	145~192	167.0	19.30	11	51.0~81.4	68.6	12.85	19
3.0~5.0	4.1	0.81	20	2.8~3.6	3.2	0.30	9	77~128	105.4	21.74	21	165~191	178.8	9.60	5	69.4~95.8	82.8	10.50	13
3.0~4.5	3.9	0.58	15	3.6~4.2	3.9	0.28	7	150~166	158.0	6.52	4	185~250	213.8	23.24	11	52.9~93.0	71.6	16.05	22
2.8~4.2	3.8	0.68	18	3.3~4.2	3.8	0.37	10	120~222	173.2	47.77	27	180~235	209.2	23.26	11	70.3~103.3	87.8	13.60	15
3.7~5.7	4.8	0.87	18	3.7~5.3	4.6	0.63	14	132~201	170.6	25.48	15	172~218	202.8	18.43	9	76.8~129.2	95.5	21.58	23
2.6~4.2	3.5	0.77	22	2.8~4.5	3.7	0.80	22	117~183	145.8	26.38	18	162~187	174.4	8.91	5	104.6~120.0	112.9	5.66	5
2.8~4.3	3.4	0.61	18	2.4~3.8	3.2	0.55	17	91~183	123.0	39.03	32	135~190	163.6	23.50	14	57.6~102.1	83.7	16.22	19
2.5~3.7	3.0	0.59	19	2.6~4.1	3.5	0.63	18	131~150	144.5	9.11	6	145~229	187.2	35.78	19	62.8~125.6	101.2	29.59	29
2.2~5.5	3.6	1.20	34	3.0~4.6	3.6	0.66	18	132~222	185.8	34.93	19	177~214	197.2	18.06	9	55.1~99.8	76.2	18.41	24
3.1~4.5	3.9	0.62	16	3.4~4.3	3.8	0.42	11	130~181	163.2	20.63	13	168~224	193.6	21.59	11	76.9~95.7	87.6	6.75	8
3.7~5.0	4.5	0.56	12	3.9~5.2	4.6	0.57	12	102~198	150.8	40.92	27	158~205	190.0	19.43	10	65.1~126.3	93.4	24.76	27
4.4~6.0	5.1	0.61	12	4.1~5.2	4.5	0.43	9	96~145	113.4	18.63	16	152~189	175.8	15.96	9	75.0~111.4	98.0	14.59	15
3.1~5.2	3.9	0.85	22	3.2~4.6	3.9	0.54	14	116~163	138.6	22.14	16	156~220	178.6	24.78	14	65.2~108.9	84.6	16.77	20
2.2~5.3	3.8	1.22	32	2.9~4.1	3.6	0.48	13	90~129	111.6	18.26	16	144~211	187.0	27.72	15	81.6~122.5	98.1	16.87	17
2.9~5.1	3.8	1.04	28	3.1~4.5	3.5	0.59	17	116~184	139.8	29.38	21	185~220	198.0	13.76	7	63.4~68.4	65.7	1.79	3
3.6~5.7	4.2	0.87	21	3.0~5.3	4.0	0.83	21	99~164	130.0	26.77	20	150~214	182.2	26.99	15	60.4~95.4	77.5	13.10	17
2.6~4.0	3.2	0.61	19	2.9~3.5	3.1	0.24	8	91~155	130.2	31.45	24	141~198	170.4	20.77	12	80.0~96.9	88.7	7.07	8
2.2~4.1	3.5	0.77	22	2.5~4.7	3.8	0.81	21	99~184	141.4	30.65	22	156~211	192.2	21.72	11	76.4~135.0	99.3	25.58	26
3.4~5.0	4.3	0.77	18	3.6~4.9	4.3	0.47	11	121~215	178.6	37.03	21	187~211	197.4	9.94	5	61.2~92.5	78.9	14.15	18
3.5~5.5	4.1	0.81	20	3.3~5.5	4.2	0.83	20	133~183	160.2	20.82	13	149~197	178.6	20.07	11	103.4~112.3	108.8	3.40	3
3.2~5.3	4.1	0.84	20	3.6~5.3	4.3	0.70	16	63~138	92.0	29.59	32	181~230	207.4	19.98	10	48.8~107.2	69.3	22.49	32
2.1~3.1	2.6	0.36	14	2.5~3.1	2.7	0.23	8	80~118	103.8	16.18	15	144~206	164.4	23.96	14	56.4~130.0	80.2	29.36	37
4.0~4.2	4.1	0.11	3	4.0~4.6	4.3	0.24	5	85~112	101.0	12.12	12	171~197	186.0	9.69	5	70.3~118.3	93.9	16.99	18
3.7~4.1	3.9	0.15	4	3.5~3.9	3.8	0.15	4	105~144	123.6	14.05	11	176~229	199.8	21.92	11	75.7~114.4	90.6	15.43	17
3.6~6.1	5.0	0.95	19	4.0~5.0	4.7	0.41	9	149~201	183.2	21.19	11	165~198	180.0	13.71	8	45.4~120.1	82.3	29.53	36
3.5~3.8	3.6	0.11	3	3.4~4.3	3.9	0.34	9	89~145	115.0	21.22	18	131~217	173.0	30.42	17	61.1~136.3	102.1	28.69	28
2.8~4.0	3.4	0.49	14	3.1~4.1	3.6	0.40	11	111~190	159.4	29.35	18	173~238	200.8	27.32	14	73.2~107.4	86.2	13.84	16
3.1~4.4	3.8	0.62	16	3.0~4.2	3.7	0.53	14	159~187	175.0	10.56	6	186~211	197.8	9.14	5	63.8~87.4	75.6	8.43	11
3.4~5.2	4.2	0.70	17	3.5~4.9	4.2	0.59	14	111~216	161.2	44.28	27	157~213	190.6	20.90	11	51.6~113.0	86.5	22.62	26
4.0~4.7	4.4	0.27	6	4.1~5.0	4.5	0.33	7	112~174	147.0	22.96	16	187~238	216.4	19.81	9	57.8~104.3	79.8	16.57	21
2.9~3.8	3.3	0.41	12	3.2~4.4	3.6	0.47	13	103~170	140.8	27.69	20	172~202	186.0	10.93	6	68.9~113.9	91.3	20.12	22
3.6~6.5	4.3	1.23	29	3.4~5.0	4.2	0.65	15	98~157	123.6	25.06	20	141~183	160.6	19.42	12	49.7~125.1	95.8	31.16	33
2.3~5.2	3.6	1.08	30	3.3~4.6	3.9	0.51	13	110~174	151.4	24.62	16	169~201	181.0	11.98	7	66.4~117.5	91.4	18.09	20
2.4~3.8	3.1	0.58	19	2.6~4.1	3.3	0.55	17	118~178	150.0	21.80	14	151~180	170.0	11.98	7	59.1~104.1	85.5	19.34	23
3.0~5.1	4.2	0.83	19	3.3~4.7	4.1	0.55	13	149~199	181.6	19.74	11	211~234	220.8	9.26	4	72.5~93.9	79.3	8.82	11
2.7~3.8	3.1	0.44	14	2.9~4.0	3.3	0.48	14	105~154	129.4	21.71	17	162~213	185.8	20.30	11	72.0~115.2	88.3	17.25	20
3.0~4.1	3.5	0.42	12	3.6~4.1	3.8	0.19	5	101~151	129.4	20.96	16	166~192	177.8	10.26	6	80.0~99.7	92.2	9.42	10
2.9~5.0	3.8	0.85	22	3.2~4.4	3.6	0.50	14	97~174	128.0	31.26	24	173~237	200.8	23.22	11	63.8~69.0	66.5	2.18	3
3.3~5.0	4.2	0.69	16	3.3~5.0	4.3	0.64	15	86~148	117.4	21.95	19	178~191	182.8	5.17	3	59.6~114.2	88.1	26.07	30
2.9~4.9	4.0	0.84	21	2.8~5.3	4.0	0.99	25	77~153	103.4	31.24	30	179~227	206.2	20.33	10	46.6~109.6	75.7	22.43	30
2.6~5.2	4.1	0.95	23	2.4~4.7	3.9	0.88	22	143~159	153.0	6.82	4	185~224	201.0	14.95	7	60.5~86.2	73.8	10.67	14
2.1~6.5	3.9	0.84	22	2.4~5.6	3.9	0.71	19	63~224	141.2	34.23	24	131~252	189.1	23.75	13	45.4~136.3	86.0	19.22	22

### 3. Analyses of variances of properties

As shown in Table 2, the properties for wood quality varied among clones. They were thus examined statistically by the analysis of variance. The results are shown in Table 3, including tree height and diameter at breast height. The numbers of degrees of freedom for clones and residuals are 45 and 180, respectively, the same through all the factors. The values were all significant at the 0.1 %, 1 %, or 5 % levels. This means that the differences exist among clones which were derived from the plus-trees selected according to the same standard based on the phenotype, planted according to a fixed arrangement of specification, and cultivated under the same soil and climatic conditions. Consequently, the differences in properties seem to mainly depend on the inherent characteristic of the parent trees. The clonal differences of such properties as growth of the diameter, basic density, and moisture content were especially greater, while those of YOUNG's modulus and tree height were comparatively lower.

**Table 3.** Analyses of variances of some properties among clones

Factors	Mean squares		F
	Clones	Residuals	
Tree heights	2.19	1.00	2.19**
Diameters at breast height	17.88	5.79	3.09***
Basic densities of heartwood	2,167.34	419.84	5.16***
Basic densities of sapwood	2,328.24	827.57	2.81***
Basic densities	1,855.05	362.31	5.12***
Average annual ring widths of heartwood	1.17	0.39	3.00***
Average annual ring widths of sapwood	1.33	0.54	2.46***
Average annual ring widths	1.22	0.32	3.81***
Moisture contents in heartwood	3,157.80	675.36	4.68***
Moisture contents in sapwood	1,326.22	373.51	3.55***
YOUNG's moduli in bending	564.47	320.54	1.76*

Notes : The numbers of degree of freedom are 45 among clones, and 180 among residuals in common with all properties. F : F values. The marks of \*, \*\*, and \*\*\* are significant at the 5, 1, and 0.1% levels, respectively.

### 4. Repeatabilities of properties

While statistically significant differences in properties were observed among clones as shown in Table 3, their repeatabilities were also calculated. Table 4 shows the repeatabilities including tree height and diameter at breast height. The numbers of degrees of freedom are 45 and 180 for clone variance and environment variance, respectively. Among the small values generally obtained, the maximum was 0.46 for basic density of heartwood and whole basic density including both heartwood and sapwood, and the minimum was 0.13 for YOUNG's modulus. The repeatability of moisture content in heartwood was high at 0.43, in spite of the fact that all the clones had a high moisture content in heartwood (so called wetwood), probably caused by the soil condition. From this fact, it is presumed that the development of wetwood is related also to environmental conditions as well as heritability. Wood properties are greatly influenced by the environment of the planted trees and the manner of their cultivation. Our previous report showed statistically significant differences in properties of the same clone among four different

seed orchards<sup>12)</sup>. This may therefore mean that good wood properties of clones can not be expected unless these clones are planted in a good environment and cultivated appropriately.

**Table 4.** Repeatabilities of some properties of clones

Factors	Variances of clone	Variances of environment	Repeat-abilities
Tree heights	0.24	1.00	0.19
Diameters at breast height	2.46	5.79	0.30
Basic densities of heartwood	355.71	419.84	0.46
Basic densities of sapwood	305.47	827.57	0.27
Basic densities	303.85	362.31	0.46
Average annual ring widths of heartwood	0.16	0.39	0.29
Average annual ring widths of sapwood	0.16	0.54	0.23
Average annual ring widths	0.18	0.32	0.36
Moisture contents in heartwood	505.31	675.36	0.43
Moisture contents in sapwood	193.93	373.51	0.34
YOUNG'S moduli in bending	49.65	320.54	0.13

Notes : The numbers of degree of freedom are 45 for variances of clones, and 180 for variances of environment in common with all factors.

## 5. Correlations

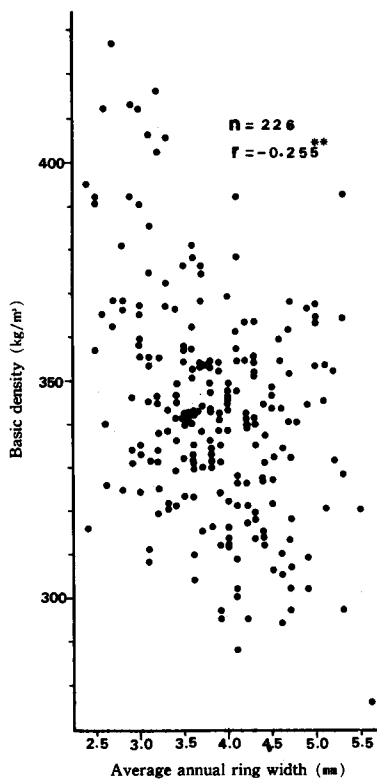
The coefficients of correlations were calculated between the two factors which seemed to be related in different properties. The results are shown in Table 5. The values of the coefficients were generally low, but the correlation between basic densities and diameters at breast height or average annual ring widths, and between moisture contents in heartwood and basic densities of heartwood or average annual ring widths of heartwood were statistically significant. This means that the smaller the diameter or the narrower the annual ring width of trees, the higher the specific gravity of wood is, and wood of a lower basic density has a larger lumen in the cells, and thus more water can be contained in it. However, the correlations between YOUNG'S moduli and basic densities or average annual ring widths were not significant. They showed low positive coefficients of 0.088 or 0.100, respectively. Generally speaking, as woods of high specific gravity or narrow annual ring width have high YOUNG'S moduli, this result is contradictory. MIYAJIMA reported also a low coefficient of correlation of 0.29 between basic densities and YOUNG'S moduli using the test pieces from planted *A. sachalinensis*, but a high coefficient of correlation of  $-0.64$  between average annual ring widths and YOUNG'S moduli<sup>3)</sup>. The reasons why significant values were not obtained in this study were probably due to the fact that the YOUNG'S moduli were measured using standing trees in which we could not obtain values of high accuracy, all the clones were young, consisting of juvenile wood which had comparatively low density, and the annual ring widths were moderate without any extremely narrow or broad widths because of similar clones.

Scatter diagrams of the relationships having statistically significant coefficients of correlations are shown in Figs. 3 and 4.

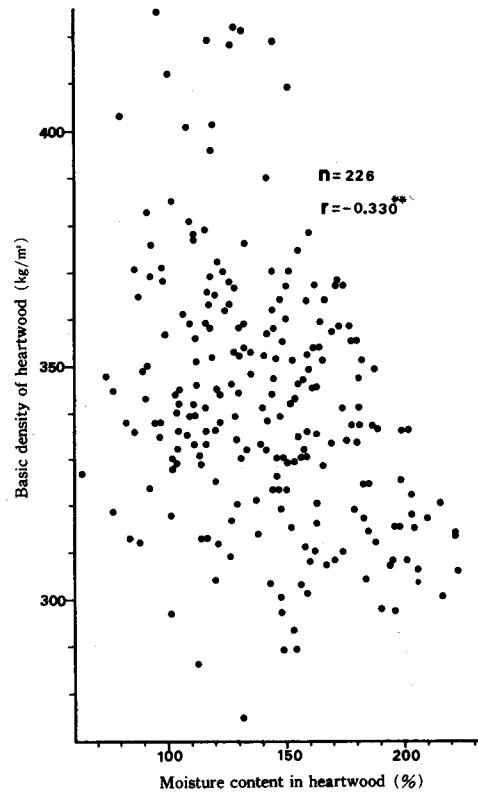
**Table 5.** Coefficients of correlation

Factors		r
Basic densities	Diameters at breast height	-0.234**
	Average annual ring widths	-0.255**
Moisture contents in heartwood	Basic densities of heartwood	-0.330**
	Average annual ring widths of heartwood	0.157*
YOUNG'S moduli in bending	Basic densities	0.088
	Average annual ring widths	0.100

Notes : r ; Coefficients of correlation, \*, \*\* ; Significant at the 5% and 1% levels. n=226



**Fig. 3.** A correlation between average annual ring widths and basic densities.



**Fig. 4.** A correlation between moisture contents in heartwood and basic densities of heartwood.

## V. Conclusion

The fundamental properties for wood quality such as basic density, average annual ring width, and moisture content were examined using 226 grafted trees consisting of 46 clones of *Abies sachalinensis*, thinned from the seed orchard of the Forest Tree Breeding Experimental Station, Hokkaido University. Prior to row thinning, measurements of tree height, diameter at breast height, and YOUNG's modulus in bending were also carried out. The values obtained were analyzed statistically.

The results are as follows :

The averages of tree height and diameter at breast height were 6.9 m and 13.3 cm, respectively, measured over a 22 year period after plantation. The averages of basic density of wood, annual ring width of wood, moisture content in heartwood, and YOUNG's modulus in the bending of standing trees were 342 kg/m<sup>3</sup>, 3.9 mm, 141.2 %, and 86.0 tons/cm<sup>2</sup>, respectively. The specific gravity calculated from 342 kg/m<sup>3</sup> of average basic density became 0.415 at 15 % moisture content, slightly less than the minimum specific gravity of 0.43 required for higher structural timber grades of *A. sachalinensis*. The reason for this is probably due to the fact that the trees were young that the wood was mainly juvenile wood. The average annual ring width of 3.9 mm was moderate, compared to the maximum of 6.0 mm according to the Japanese Agricultural Standard. The average moisture content of 141.2 % was very high and almost all the clones had a moisture content of more than 100 %, wetwood, even though a clonal significant difference was shown. The cause of this high moisture content in heartwood, therefore, seems to be the soil of the seed orchard which is composed of several layers of thick wet peat. The 86.0 tons/cm<sup>2</sup> of the YOUNG's modulus belongs to E90 for structural timber according to JAS<sup>13)</sup>. Among clones, statistically significant differences of these properties were shown by the analysis of variance. The repeatabilities, heritabilities as a broad sense, of the properties were low, reflected in 0.13 for YOUNG's modulus to 0.46 for basic density. This implies that wood properties are greatly influenced by the environmental conditions of the planted tree. Correlations between two factors apparently related in properties were also low, the coefficient of which were, however, statistically significant between basic densities and diameters at breast height or annual ring widths, and between moisture contents in heartwood and basic densities of heartwood or annual ring widths of heartwood, and not significant between YOUNG's moduli and basic densities or annual ring widths.

Finally, we conclude that in order to obtain good wood properties in planted trees cultivated from seeds obtained from a seed orchard, a good environment for plantation and appropriate management are needed, even though the seeds produced from the clones of plus-trees, are of excellent quality.

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\* : in Japanese. \*\* : in Japanese with English title and summary.

## 摘 要

トドマツ (*Abies sachalinensis* MAST.) は材が軟らかく、辺・心材とも黄白色で、木理が通直なので、建築材として広く賞用されている。しかし、しばしば低比重で年輪幅が広すぎる材や、心材含水率が異常に高いいわゆる水食い材が発生し、利用上大きな問題となっている。

本研究では、北海道大学林木育種試験場に造成しているトドマツ採種園の列状間伐にあわせて、1993年4月に試料を採取し、基礎的な材質である容積密度数、平均年輪幅、および含水率を測定した。間伐に先立ち、ランダムに1クローン当たり5ラメットを目処に試料を選定し、その樹高と胸高直径を求め、さらに強度の指標となる立木の曲げヤング係数を測定した。試料の合計数は46クローン、226本であり、いずれも道北の天然林において選抜されたトドマツ精英樹からつぎ木によって増殖され、1971年に49型の配置で採種園に植栽されたものである。材質測定のためのサンプルは、胸高付近の厚さほぼ5cmの円盤で、伐採後は直ちにビニール袋に入れて実験室に運び、髄を通る直方体に切断し、さらに心・辺材に分けて標準法に準拠して、上記試験を実施した。つぎに得られた数値について統計処理を行って解析した。ただ今回の試料は、植栽後22年という若齢木である上、採種園という管理のゆきとどいたところから採取したものであるため、一般の建築に用いる造林木とは異なる。しかし、その産地が明確であり、同一の条件で育成された樹木であること、また遺伝的に同じクローンを材料としているので、この研究により、クローン間の材質の相違や、遺伝率、あるいは種々の材質間の相関等多くの有効な情報を得ることができた。

試験の結果は、次のようにまとめられる。

1. 植栽後22年のつぎ木トドマツクローンの平均樹高および胸高直径は、それぞれ6.9mと13.3cmであった。
2. 心・辺材を含む容積密度数と平均年輪幅、心材含水率および樹幹の曲げヤング係数の全体平均値は、それぞれ $342 \text{ kg/m}^3$ 、3.9mm、141.2%、および $86.0 \text{ ton/cm}^2$ であった。
3. 平均容積密度数  $342 \text{ kg/m}^3$  を15%含水率の比重に換算すると、0.415となり、日本農林規格で定めているトドマツ等針葉樹II類の建築用上級構造材の最低比重0.43にはわずかに及ばなかった。
4. 平均年輪幅3.9mmは適度な値であり、同規格の最高値6mmには達していない。
5. 平均心材含水率141.2%は極めて高く、1クローンを除いて、いずれも100%を超えており、いわゆる水食い材といえよう。この理由は明確ではないが、試料が泥炭地に植栽されており、土壌が常に過湿であったためと考えられる。
6. 樹幹曲げヤング係数の平均 $86 \text{ ton/cm}^2$ は、1991年から構造用製材に適用された同規格のE90( $80 \text{ ton/cm}^2$ から $100 \text{ ton/cm}^2$ まで)に属し、6等級区分中の中間に位置し、道南のスギにくらべかなり高い値である。

7. 分散分析によって、これらの材質はいずれもクローン間で有意であった。これらのクローンは、同じ基準で選抜された精英樹で、同じ環境に植栽されていたものであるので、このことはそれぞれクローン毎に固有の性質をもつことを意味している。また、心材含水率が全体的に高くても、クローンによりやはり違いがあることが分かった。

8. 各材質の広義の遺伝率といわれる反復率を算出したところ、その値はヤング係数の0.13から、容積密度数の0.46までの範囲であり、いずれも低かった。これは各材質とも環境によって、かなり変動することを意味している。

9. 各材質中、相互間で関連があると思われる因子について相関を求めたところ、いずれの相関係数も低かった。しかし、心材含水率と心材容積密度数、および同含水率と同年輪幅の間には有意な相関が認められた。これは、容積密度数が低いもの程、また年輪幅が広いもの程、一般に細胞の内腔が大であり、そこに水が入っているものと推察される。

10. 一方、樹幹曲げヤング係数と容積密度数、および同ヤング係数と年輪幅の間には、相関が認められず、これまでいわれている結果とは異なっていた。これは、今回のヤング係数測定の応力レベルが10 kg/cm<sup>2</sup>と小さかったため、精度がやや低かったことと、いずれも同一の基準で選抜した精英樹からのクローンなので、極端な容積密度数や年輪幅の値が得られなかった結果であろうと推察している。

11. 以上、各材質を調べた結果から、たとえ精英樹のクローン同士によって得られた優秀な種子から育成された樹木であっても、その優れた材質を発揮するためには、やはり造林に際して適地を選ぶこと、そして適切な管理を行うことが必要であると結論される。