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Effects of radial growth rate on selected indices for juvenile and mature wood of the Japanese larch

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Abstract To examine the differences between juvenile and mature wood, 12 aged sample trees from two areas of Nagano Prefecture were harvested; and the radial development of tracheid length, the ring density, and the relation of the radial growth rate (observed by ring width) with some selected indices of ring structure were investigated. The results proved that the radial variation of tracheid length with ring number can be described by a logarithmic formula, and both plantations reached the demarcation of juvenile and mature wood at age 18. With the segmented regression method, we also analyzed radial variation of mean density and found that the demarcation of juvenile and mature wood was at age 15 for sample trees from Saku and at age 21 for those from Yabuhara. By using the results of estimates from juvenile and mature wood based on ring density, we found that high growth rates resulted when producing lower-density wood during the juvenile period, but these rates did not occur during the mature period. The basic reason for this phenomenon is the variation in patterns of earlywood and latewood in juvenile and mature wood, respectively. This result advised us that when managing plantations of Japanese larch it is necessary to take different measurements at different growth periods.

Key words Juvenile wood · Mature wood · Tracheid length · Ring density · *Larix kaempferi* Carriere

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Introduction

The properties of juvenile wood differ from those of mature wood.[1] Explication of the differences between them has created an increasing need to regulate wood structure and thus the properties of wood by altering forestry management methods.

In fact, much research has been done on the differences between juvenile and mature wood and the properties of juvenile wood,[1,2] and many conclusions have been drawn. Among them, though, few studies have been concerned with the relations of the radial growth rate (observed by ring width) with other indices of annual ring structure by distinguishing juvenile and mature wood. The latter distinction is thought to be a vital theme when providing information about effective plantation management. Even with the few studies reported, the results have been controversial. Koga et al.[3] pointed out that there was no significant correlation between basic density and annual ring width in mature wood of Japanese cypress (*Chamaecyparis obtusa*) or in Japanese larch (*Larix kaempferi* Carriere). A similar conclusion was made in a wood quality study on trees of Japanese larch.[4] In contrast, Koizumi et al.[5] and Takata et al.[6] reported that in outerwood, as in corewood, the basic density showed a decreasing trend with increasing ring width for Japanese larch.

Up to now, the sample trees of Japanese larch used in most studies were very young, and most of them came from thinning wood. Therefore, it was difficult to consider these conclusions reliable. In a previous report[7] we specifically investigated the relations between annual ring width and ring density, earlywood and latewood width, and percentage of latewood in corewood (juvenile wood) and outerwood (mature wood), respectively, for Japanese larch. It was thought, however, that the conclusions were also not convincing enough because of the small sample size and the single source of the sample trees. Therefore, in this study we harvested an additional 12 aged sample trees from two areas of Nagano Prefecture, including six trees that were 106 years old, and attempted to attain a conclusive result.

Table 1. Basic information for sample trees

Sample tree	Tree age (years)	Height (m)	DBH (cm)	Clear length (m)
S1	106	31.0	70.0	14.8
S2	106	30.4	66.0	16.8
S3	106	32.5	72.0	14.3
S4	106	30.6	46.0	13.7
S5	106	30.8	48.0	16.9
S6	106	30.3	44.0	19.0
Y1	73	24.0	38.0	15.5
Y2	73	27.2	54.0	11.6
Y3	73	28.2	44.0	11.0
Y4	73	31.2	36.0	16.4
Y5	73	23.1	34.0	13.1
Y6	73	31.7	46.0	13.7

S, sample trees from Saku; Y, sample trees from Yabuhara; DBH, diameter at breast height

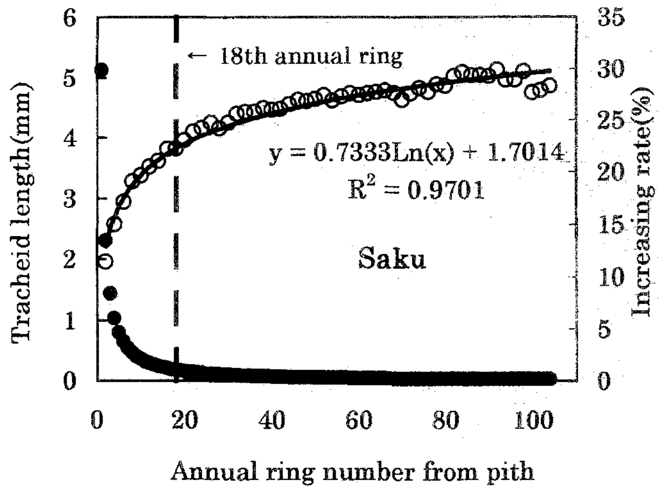

Fig. 1. Variation of tracheid length and its increasing rate in the radial direction for Saku plantation (mean value of six sample trees). *Open circles*, tracheid length; *filled circles*, increasing rate; *solid line*, logarithmic curve

Materials and methods

The experimental plantation for our previous research was located in Shinshu University Forest in Terasawa Yama, in the southern part of Nagano Prefecture.[7] This time two another plantations were chosen. One was located in Saku, in the eastern part of Nagano Prefecture; and the other was in Yabuhara, at the middle of Nagano Prefecture. The Saku plantation was planted in 1892 with an initial stock of 6600 stems/ha; from 1903 to 1952 it had been used as thinning experiment.[8] In 1924, Japanese cypress had been interplanted. The plantation was situated about 975 m above sea level at the foot of Mt. Asama on a moderate slope. The Yabuhara plantation was planted in 1925 and was thinned once in 1953.

Six dominant trees were selected from each plantation. All trees selected were straight with uniform crowns, and they were free from lean and visible defects. The trees were felled, and discs approximately 10 cm thick were removed at 4-m intervals starting at breast height to a top level along the stem from each tree. The total height and the height to the base of the live crown (clear length) were measured for all trees. A summary of basic information for the sample trees is presented in Table 1.

The sample preparation and measurement of annual ring structure were the same as in our previous report.[7] For tracheid length measurement, from pith to bark, annual rings with an even number at different tree heights were measured. The sample of each annual ring was macerated in Schulze solution[9] for 2–3 days, and the tracheid lengths of latewood were measured with a universal projector. About 60 tracheids were measured per annual ring, and the average tracheid length was retained for further analysis.

To estimate the age of demarcation between juvenile and mature wood, segmented regression[10] was used for ring density. The segment of mature wood was fit to ensure that the actual slope was not significantly different from zero, and the segment from the juvenile period was fit to ensure that the slope was significantly different from zero in all cases. The juvenile and mature data were recombined to perform a segmented regression to minimize the combined residual sum of squares for both regressions. The joint point of the two segments was taken as an estimate of the age of demarcation between the juvenile and mature wood.

Results and discussion

Radial development of tracheid length

Shiokura[11] used a logarithmic formula to describe the radial variation in tracheid length with ring number and then calculated the percentage of annual increment of tracheid length. The point at which the annual increment of the length decreased to 1% was considered to be the boundary between juvenile and mature wood. We used the same method to analyze the variation in tracheid length in the radial direction. Although sample tree ages and production areas were different for Saku and Yabuhara, they showed a similar logarithmic pattern (Figs. 1, 2), which was consistent with Shiokura's results. In fact, such a pattern was well known, especially for the softwoods, and has been reported in other studies.[12,13]

From Figs. 1 and 2 we found that tracheids were short near the pith and then increased in length rapidly and nonlinearly, which was a main characteristic of the juvenile wood.[11,12,14] Near the bark, however, there was a decreasing trend in tracheid length. Trees from both plantations reached a 1% annual increment in tracheid length at age 18. Therefore, the 18th annual ring was considered the demarcation between juvenile and mature wood when differentiated by tracheid length.

Radial development of ring density

The developmental trend of ring density for each sample tree from both Saku and Yabuhara was carefully examined;

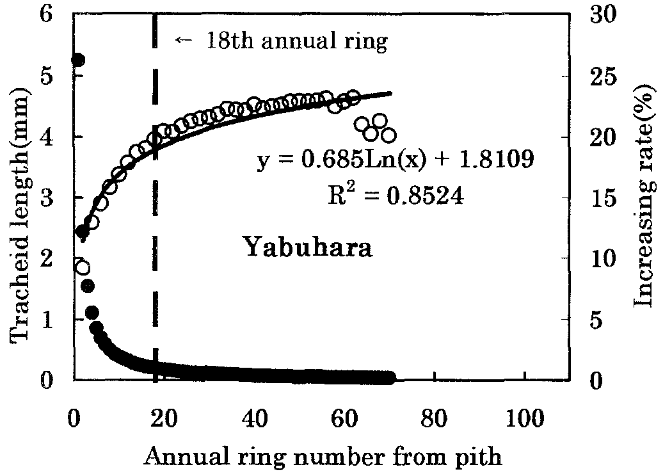

Fig. 2. Variation of tracheid length and its increasing rate in the radial direction for Yabuhara plantation (mean value of six sample trees). *Open circles*, tracheid length; *filled circles*, increasing rate; *solid line*, logarithmic curve

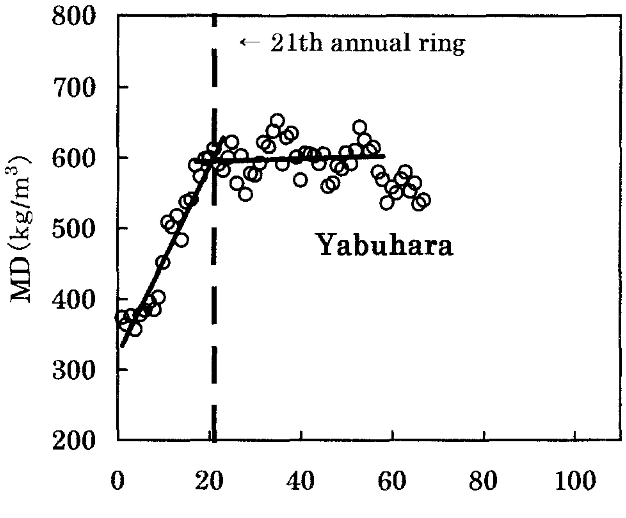

Fig. 4. Variation of the mean density in the radial direction for Yabuhara plantation (mean value of six sample trees). *Circles*, mean density; *solid line*, segmented regression line

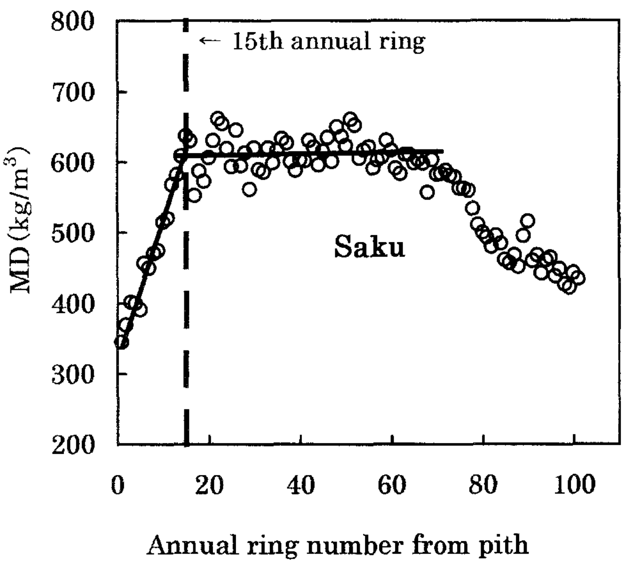

Fig. 3. Variation of mean density (*MD*) in the radial direction for Saku plantation (mean value of six sample trees). *Circles*, mean density; *solid lines*, segmented regression line

and it was found that all sample trees from the same plantation displayed similar trends in the radial direction. Therefore, we used the average value of six sample trees to illustrate the variation in trend for the two plantations.

As seen in Fig. 3, the average ring density at Saku plantation increased sharply until about age 15 and then stabilized, showing little change with increasing age until age 70, after which it decreased with age. Usually, the age of demarcation between juvenile and mature wood is considered to be the age at which the ring density begins to remain constant.[10] By using segmented regression, we found the age of demarcation between juvenile and mature wood to be 15 years, which agreed with most results reported up to now.[15,16] For the sample trees from Yabuhara, although the average ring density presented a variation in trend similar to that in the Saku sample trees (Fig. 4), the segmented regression lines crossed at age 21, delaying the mature period for 6 years compared to the Saku trees. The reason for this delay was not evident, but a similar observation has been made in red pine from different plantations;[17] that study concluded that the point of maturity for a given property may vary by more than 10 years among stands.

It has been pointed out that differences exist among wood quality indices when estimating juvenile and mature wood;[1,2] and similar to our results, the estimate of their demarcation by fiber length was different from that derived by ring density. From the point of practical use, we think the estimate of juvenile wood based on ring density is more reasonable, so in the present research 15 years of age for Saku plantation trees and 21 years for Yabuhara trees were used to demarcate juvenile and mature wood. These distinctions were used when discussing the relations between radial growth rate and other indices of ring structure.

Relation of radial growth rate with some selected indices of ring structure

As shown in Fig. 5a for Saku plantation trees, with increasing annual ring width (ARW) the mean density (MD) in juvenile wood decreased significantly, whereas the MD in mature wood increased at first and, after about 1.5 mm in ARW, remained more or less constant or tended to decrease slightly. This means that during the growth period of Japanese larch a higher radial growth rate results in producing lower-density wood during the juvenile period; but during the mature period maintaining a high growth rate does not markedly reduce wood density. Moreover, conversely, a much lower growth rate (when ARW is less than about 1.5 mm) may result in lower wood density. In other words, wood density is negatively related to growth rate during the

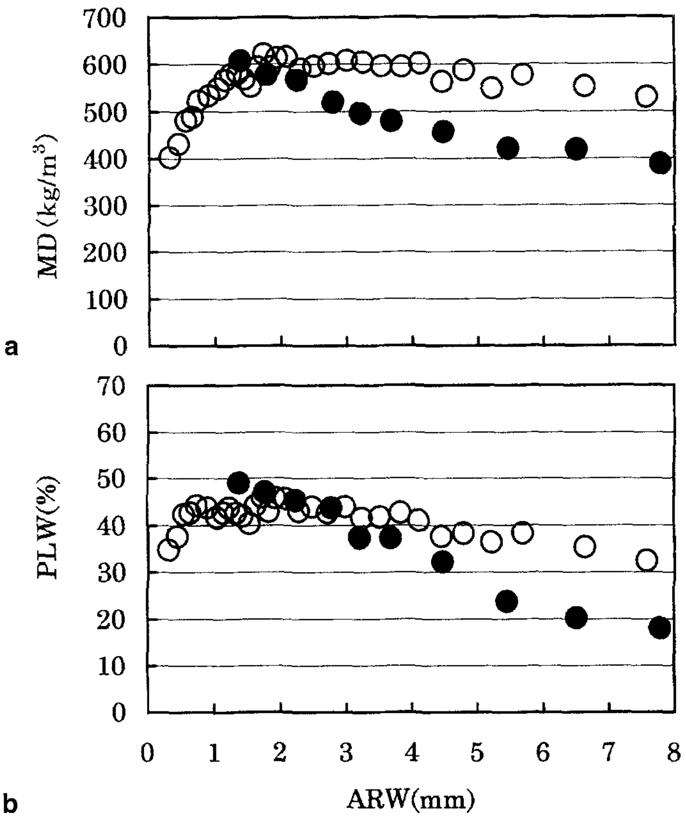

Fig. 5. Relation between annual ring width (*ARW*) and (**a**) mean density (*MD*) and (**b**) percentage of latewood (*PLW*) for Saku plantation. *Filled circles*, juvenile wood; *open circles*, mature wood

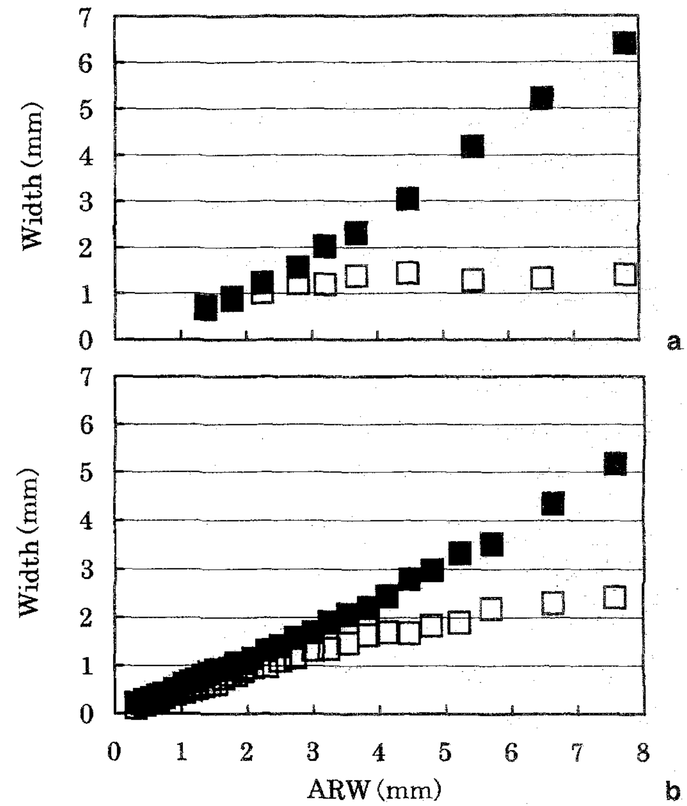

Fig. 6. Relation between annual ring width and earlywood width, latewood width in juvenile (**a**) and mature (**b**) wood for Saku plantation. *Filled squares*, earlywood width; *open squares*, latewood width

juvenile period and has no correlation with growth rate during the mature period, as reported previously by Zhu et al.[7]

Figure 5b shows the relation between the ARW and the percentage of latewood (PLW), which well explains why the relation existed between ARW and MD in both juvenile and mature wood. Moreover, as shown in Fig. 6, with increasing ARW the earlywood width increased proportionally and the latewood width remained more or less constant in juvenile wood; both increased proportionally in mature wood. As a result, the PLW decreased significantly with increasing ARW in juvenile wood and remained relatively constant or tended to decrease slightly in mature wood (Fig. 5b), determining the variation in trends of MD.

The above results were from sample trees of the Saku plantation, with a tree age of 106 years. In fact, the 73-year-old sample trees from Yabuhara plantation showed the same properties (Figs. 7, 8), and all of the results agreed with those from our previous research.[7] Small differences were observed between the sample trees from Saku and Yabuhara Plantations. The increasing slope of latewood width in mature wood with increasing ARW from the Saku trees (Fig. 6b) was somewhat smaller than that for the Yabuhara trees (Fig. 8b), resulting in a slightly decreased PLW in mature wood. The reason may be the short summer and autumn in Saku, which shortens the growth period and limits the formation of latewood.

From above discussions it appears that the influence of growth rate on wood density was different during the various growth periods, and discriminating juvenile and mature wood is necessary when studying the relation of wood density with growth rate, which is of crucial importance to forest managers for harvesting quality wood from intensively managed plantations.

Conclusions

Based on the results from this study on sample trees of Japanese larch from different plantations and with different ages, the following conclusions were reached.

1. The fact that radial variation in tracheid length with ring number can be described by a logarithmic formula was proved; and in this study both plantations reached the demarcation of juvenile and mature wood at age 18 when differentiated by tracheid length.

2. By analyzing the radial variation in mean density with the segmented regression method, the demarcation of juvenile and mature wood occurred at age 15 for sample trees from Saku and at age 21 for Yabuhara trees, which proved that there were differences among the various wood quality indices for estimating juvenile and mature wood. Even for a same quality index, the point of maturity may vary in different plantations.

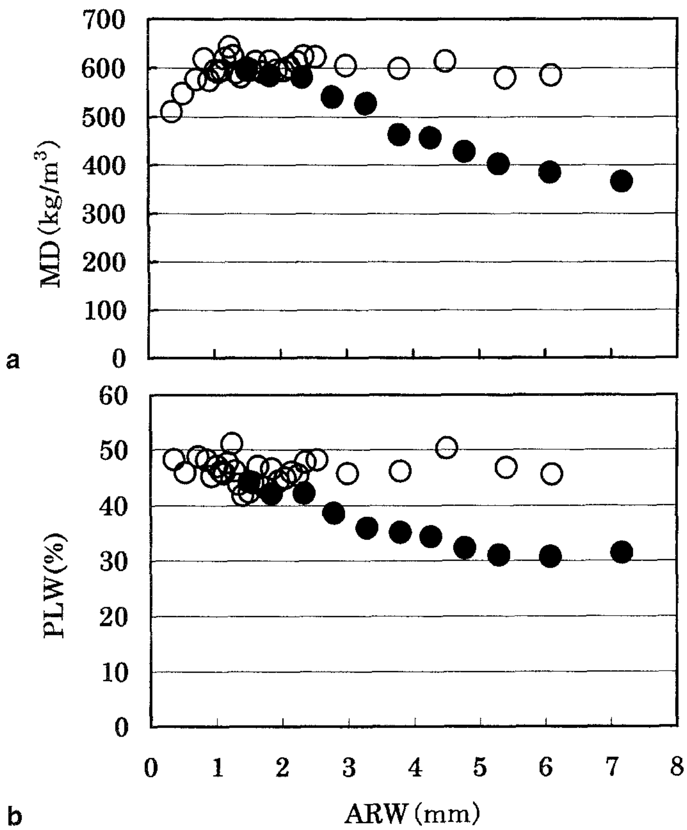

Fig. 7. Relation between annual ring width and (**a**) mean density and (**b**) percentage of latewood for Yabuhara plantation. *Filled circles*, juvenile wood; *open circles*, mature wood

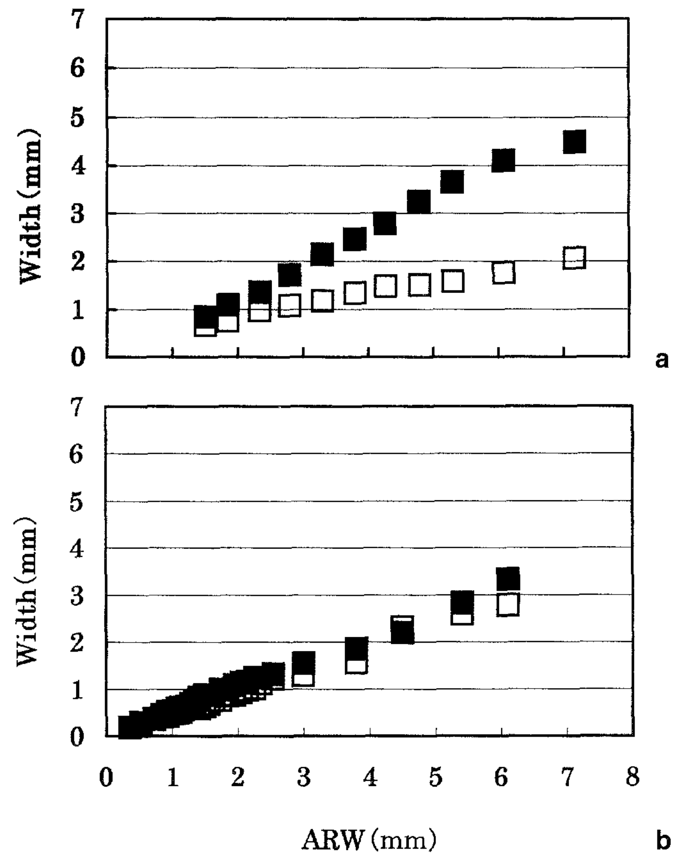

Fig. 8. Relation between annual ring width and the earlywood width and latewood width in juvenile (**a**) and mature (**b**) wood for Yabuhara plantation. *Filled squares*, earlywood width; *open squares*, latewood width

3. By using the estimates for juvenile and mature wood based on ring density, it was found that a higher growth rate resulted in the production of lower-density wood during the juvenile period but not during the mature period. The basic reasons for this phenomenon ensure the variations in the patterns of earlywood and latewood in juvenile and mature wood. This result suggested that taking different measures during different growth periods is necessary when managing plantations of Japanese larch.

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