GROWTH AND WOOD PROPERTIES OF RAPID-GROWN JAPANESE LARCH

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ABSTRACT

Japanese larch grown under intensive management practices (i.e. fertilization, irrigation, and cultivation) exhibited rapid juvenile growth; diameter and height averaged 15.7 cm and 9.2 m, respectively, in 10 yr. Whole-ring specific gravity decreased for several years after fertilization and then increased; it was influenced by the presence of large amounts of transition wood and low latewood percent. X-ray analysis also showed that specific gravity was quite uniform within the annual rings after fertilization. The percentage of extractives was low throughout the trees; this may have been related to the absence of heartwood formation. The pattern of both latewood percent and percent of extractives indicated that the juvenile wood zone in these trees was 10 yr. Furthermore, compression wood was present in most annual rings although it was primarily associated with the latewood. The possibilities of selecting for growth and wood properties in a tree improvement program for Japanese larch are discussed.

Additional keywords: *Larix leptolepsis*, specific gravity, extractive content, latewood, compression wood, juvenile wood, wood quality.

INTRODUCTION

One of the species currently under consideration for meeting the increased demand for fiber is young Japanese larch (Jeffers and Isebrands 1974). It is known to combine good form with rapid juvenile growth, and to grow well under intensive management (Schreiner 1970). However, Japanese larch occurs only in scattered plantations in the Northeast and North Central states, and has had only limited use.

Although larch wood has been used extensively for pulp throughout other parts of the world (especially in northern Europe and Russia), it has not been highly regarded for fiber. The prejudice against larch is based upon a misconception that it yields less pulp than most other conifers (Jeffers and Isebrands 1974). When lower pulp yields are derived from larch, it can be attributed primarily to the large quantities of resin and water-soluble extractives (arabinogalactans) present in larch heartwood that interfere with cooking in the sulphite process and bleaching in the kraft process (Leatheart 1969; Nevalainen and Hosia 1969). Unfortunately, most of the larch harvested for pulp in the past has been either slow-grown or old-growth wood (Hakkila and Winter 1973), both of which have high heartwood content that accentuates the resin and extractive problems. Furthermore, much of this wood has been pulped by the sulphite process, which has been shown to be inefficient for pulping larch (Nevalainen and Hosia 1969).

Research has demonstrated that larch can be a suitable raw material for kraft pulping (Perry and Cook 1965), and that larch kraft pulps often resemble southern pine kraft

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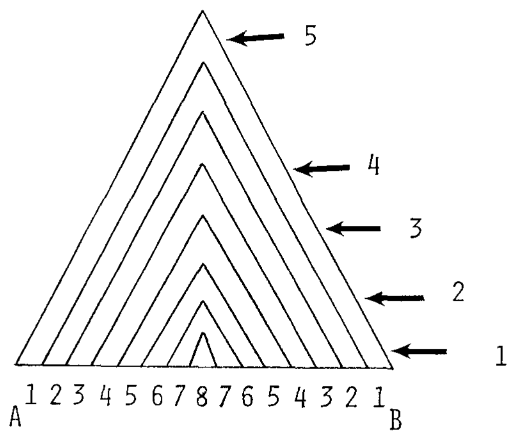

FIG. 1. Location of the 5 sampling heights along the boles of the trees (arrows), (1) base-stump height, (2) base of live crown, (3) midpoint of tree, (4) midpoint of live crown, and (5) base of previous year's growth. At each height all annual rings across the diameter were sampled and numbered from pith to bark for radii A and B.

pulps (Nevalainen and Hosia 1969; Hakkila et al. 1972).

Many of the problems of larch utilization for pulp could be improved by the use of younger trees. For example, young larch consists largely of sapwood, which is lower in both resin and extractive content; consequently, it is easier to pulp than older larch (Uprichard 1963). Although young Japanese larch may have some wood properties that are inferior to those of mature wood, it compares favorably to other coniferous species in its physical pulp properties (Packman 1966).

In recent years the use of juvenile wood of conifers has increased significantly; furthermore, juvenile wood is becoming recognized as an acceptable source of fiber raw material for many pulp products (Zobel et al. 1971). Stonecypher and Zobel (1966) also have shown that juvenile wood exhibits much potential for tree improvement programs. These facts, coupled with the prospect that juvenile larch wood may not have the utilization problems associated with older larch wood, led us to the present investigation of juvenile wood of Japanese larch.

The objectives of this study were to evaluate the juvenile growth and wood properties of 10-yr-old Japanese larch trees selected for rapid growth and grown under intensive management. Such information will allow us to make some preliminary comparisons with juvenile wood of more accepted pulp species and to investigate the possibilities of selection for growth and wood properties for subsequent tree improvement programs.

MATERIALS AND METHODS

In the spring of 1963, five hundred 2-0 Japanese larch[2] seedlings selected for rapid growth from the nursery bed were planted at 2.45- × 2.45-m spacings on well-drained nursery soil at the Washington Crossing State Nursery near Trenton, N.J. Competing vegetation was reduced by periodic mowing and chemical treatment. The trees were irrigated regularly throughout the season when weekly rainfall fell below 2.5 cm. In 1965 and 1966, between 50–60 g of 10-10-10 fertilizer was applied per tree in the spring, mid-June, mid-August, and in late September. A single fertilizer application was made in July 1967; another in June 1970. After the 1968 and 1969 growing seasons, the stand was thinned to maintain full vigorous crowns.

Height and diameter were measured annually from 1966 to 1971. At the end of both the seventh and eighth growing seasons in the field (ages 9 and 10), cross-sectional discs were collected at 5 positions on the bole—(1) base of the tree, 0.1 m, (2) base of crown (approx. 1.8 m), (3) midpoint of tree (4) midcrown, and (5) base of previous year's growth (arrows, Fig. 1). Nine trees were harvested at age 9 and analyzed for volume (bark free), bark thickness, bark percentage, and bark/wood ratio (dry weight basis).[3] In addition, six trees were harvested at age 10. At each of the five heights on the stem, whole-ring specific gravity and percent of extractives were determined for each annual ring from bark to

[2] Commercial source of seed from Japan (Herbst Brothers, Brewster, N.Y.).

[3] Bark thickness was measured with binocular microscope, and bark/wood ratio was determined on an oven-dry weight basis.

pith on radii A and B as depicted in Fig. 1. Specific gravity (unextracted) was determined by the oven-dry weight-green volume method using water immersion for volume determination. Percent extractives was determined on small radial wafers by extracting in 95% ETOH:benzene (1:2) for 16 h, followed by 6 h extraction in 95% ETOH and then 2 h in hot water. Percent extractives were expressed on the basis of extracted oven-dry wood.

From two of the trees, transverse microtome sections (20 μm) were cut from each ring at each height shown in Fig. 1. On these sections latewood percent was measured, and incidence of compression wood and other anatomical observations were made. Little or no latewood was present conforming to Mork's definition: therefore, for our material we defined the latewood boundary as the abrupt transition of radial cell diameter present in the annual ring. Because the actual percentage of compression wood in a ring cannot be determined easily, the incidence of compression wood tracheids was scored instead. In each annual ring we determined whether it was high, low, or merely present; its presence in the earlywood, latewood, or transition wood of the ring was also noted.

RESULTS AND DISCUSSION

Growth

The growth of this plantation was impressive (Table 1). At the end of 3 yr in the field (5 yr from seed), the trees averaged 2.3 m in height. After 7 yr, the stand averaged 7.9 m in height and 13.2 cm in diameter (dbh) with a bark-free volume of over 0.08 m³ per tree. The largest tree was 9.5 m tall and 16.3 cm dbh. After nine growing seasons (age 11), the plantation averaged 10.1 m in height and 16.5 cm in diameter.

Unfortunately, little information is available about the growth performance of selected Japanese larch seedlings on good sites. In comparison to other Japanese larch stands grown in the United States under less intensive management, the trees in this study show remarkably faster growth. For example, Crow (1966) reported that a Japanese larch source in a lower Michigan plantation was only 3.5 m in height after 8 years from seed. Similarly, Farnsworth et al. (1972) reported that Japanese larch provenances in Minnesota and Iowa were 3.0 m tall after 7 yr., while one in Nebraska was 7.0 at age 12. In Vermont Japanese larch averaged 10.7 m in height and 17.8 cm at dbh at age 14 (Turner and Myers 1972). However, it should be emphasized that our plantation was grown from selected stock at a more southern latitude than most other Japanese larch plantations, and their growth rate was similar to that of fertilized southern pine plantations in Mississippi (Schmidtling 1973) and South Carolina (Van Lear et al. 1973).

TABLE 1. *Average diameter and height of rapid-grown Japanese larch at Washington Crossing, N.J.*[a]

Years in field	Age from seed	Diameter (DBH, cm)	Height (m)
3	5	----	2.3
4	6	----	3.6
7	9	13.2	7.9
8	10	15.7	9.2
9	11	16.5	10.1

[a] 2-0 nursery selected seedlings planted in 1963. Measurements taken at end of growing season.

The growth and form of individuals in the plantation varied considerably. After eight growing seasons, it was apparent that certain trees had responded to the cultural practices better than others in terms of growth. Similarly, some individuals showed better form (e.g. were much straighter and had fewer branches) than the average tree in the stand.

Wood properties

Specific gravity

Specific gravity is useful in tree improvement research because it provides an easily measured index of wood properties and wood yield and has strong heritability. Whole-ring specific gravity within our trees ranged from 0.29–0.66 with most specific gravity values in the lower bole (sampling

TABLE 2. *Specific gravity values within an individual rapid-grown Japanese larch tree. Sampling positions conform to those shown in Fig. 1*

Sampling height	Specific gravity															
4	0.312	0.306	0.356	0.325								0.325	0.370	0.305	0.297
3	0.326	0.342	0.327	0.351	0.412						0.412	0.360	0.291	0.315	0.368
2	0.359	0.354	0.345	0.327	0.316	0.411				0.379	0.346	0.347	0.324	0.334	0.391
1	0.441	0.356	0.398	0.388	0.354	0.370	0.410	—	0.430	0.348	0.362	0.327	0.320	0.340	0.420
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	B_7	B_6	B_5	B_4	B_3	B_2	B_1
Bark								Pith							Bark
	Annual growth sheath increment number														

heights 1 and 2 of Fig. 1) ranging from 0.30–0.45. This range of juvenile wood specific gravity near the stem base of our trees is similar to that of juvenile wood of other pulp species: 0.28–0.35 in Douglas-fir (Megraw and Nearn 1971); 0.35–0.39 in loblolly pine (Zobel et al. 1971); and 0.42–0.47 in European larch (Pearson and Fielding 1961).

Because of inherent differences between trees, several trees from our sample consistently had higher specific gravities overall. However, even though the specific gravity of any particular ring was different between trees, the same general trends occurred within individual trees. These trends are typified by the data for an individual tree shown in Table 2. Because the sampling positions between trees were not at the exact same height, the specific gravity data were not averaged. Within most growth sheath increments, specific gravity decreased with height (e.g. rings A1, A2, B1, and B2). This is a characteristic trend within most conifers (Panshin and DeZeeuw 1964). Table 2 also demonstrates the pith to bark variation of specific gravity observed at each given sampling height. This trend is not typical for most conifers. For example, at the two lowest sampling heights (height 1 and 2 of Table 2) specific gravity was high near the pith, followed by a decrease for several growth rings and then an increase.

Therefore, since we were interested in the factors influencing these trends, we decided to examine the radial variation of specific gravity within the trees in more detail. One of the best ways of evaluating this variation is through X-ray analysis, which allows one to examine the intimate changes that occur within each annual ring (Parker et al. 1973). It is also particularly useful for tree improvement in assessing the effect of silvicultural treatments on specific gravity (Megraw and Nearn 1971). An X-ray densitometer trace of a basal radius corresponding to sampling height 1 of Fig. 1 illustrates the usefulness of the technique for evaluating our material (Fig. 2).[4]

Typically, specific gravity within the annual ring of larch increases sharply from earlywood to latewood much like the pattern shown by the '70 ring of Fig. 2 (see also Hakkila and Winter 1973). However, in our trees there was a distinct increase in uniformity of specific gravity across the ring (e.g. ring '68), and the relative specific gravity of the uniform wood was lower than the previous annual ring (compare ring '68 with ring '67 in Fig. 2). This meant that the whole-ring specific gravity after fertilization was lower. Approximately two years after fertilizer treatment, the pattern of specific gravity gradually returned to a more

[4] The authors wish to thank Dr. Robert Megraw, Weyerhaeuser Corp., Seattle, WA. for providing the X-ray densitometer traces. The trace shown in Fig. 2 is calibrated for Douglas-fir; therefore, it indicates relative, and not absolute values.

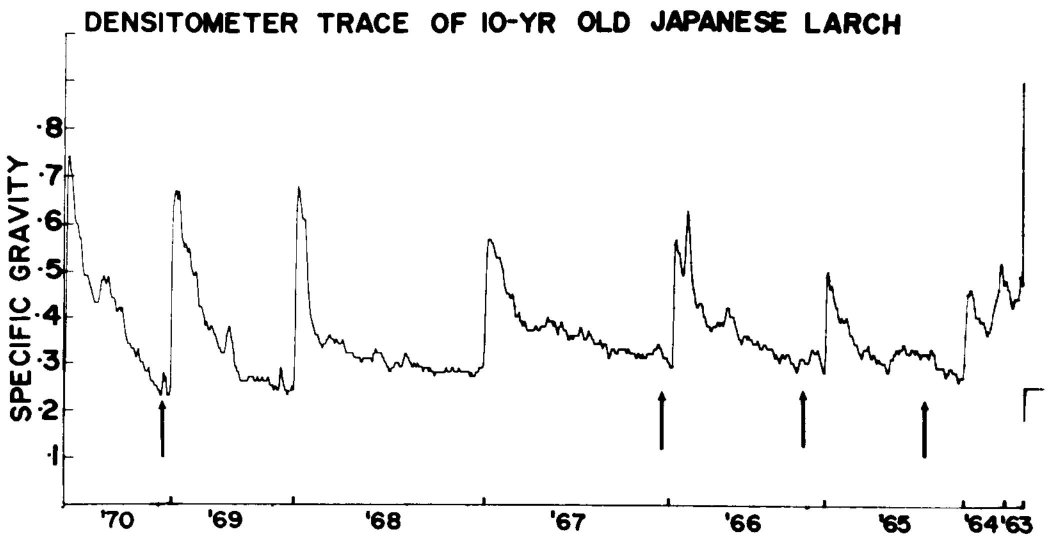

FIG. 2. X-ray densitometer trace of a basal radius of a rapidly grown Japanese larch. The sampling position corresponds to height 1 in Fig. 1. Specific gravity values in this figure are only relative since the trace was calibrated for Douglas-fir. Arrows refer to points of fertilizer application.

typical pattern (rings '69 and '70). These observations have also been made in fertilized Douglas-fir by Erickson and Harrison (1974).

We suggest that the decreasing and then increasing trend of whole-ring specific gravity variation shown earlier (heights 1 and 2 of Table 2) can be partially explained as a response to fertilizer. The total response is one of decreased specific gravity, decreased latewood percent, and increased uniformity within the annual rings as shown in Fig. 2, and explained above. Such trends can be properly assessed only by a within-ring evaluation such as provided by the X-ray technique.

Gladstone and Gray (1973) also found uniform specific gravities within annual rings of fertilized red pine. Furthermore, Klemm (1967) concluded that fertilization greatly increased the homogeneity of all wood properties in conifers. Uniform wood properties within rings such as reported here improve the efficiency of processing the raw material. Therefore, even though the overall effect of intensive management practices on this stand may be to decrease specific gravity on a whole-ring basis, the corresponding increase in unformity coupled with increased volume production would undoubtedly outweigh the decline in specific gravity.

Transition wood anatomy

The increased uniformity within the annual ring of fertilized trees, which is desirable in terms of utilization, is associated

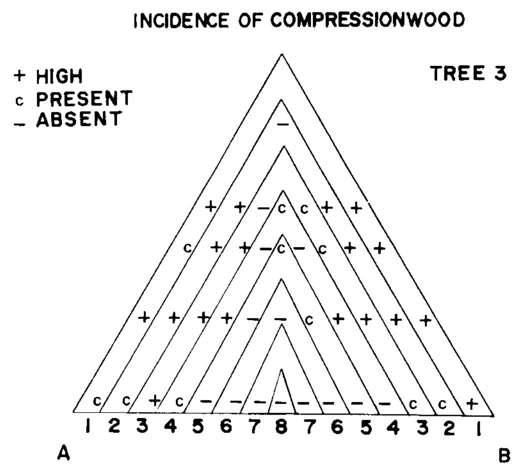

FIG. 3. Incidence of compression wood within the stem of tree 3.

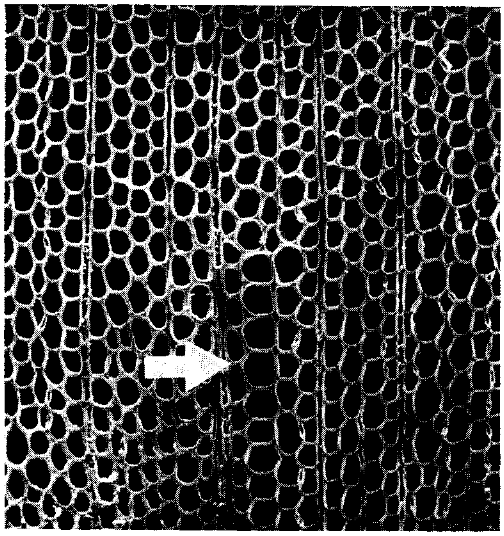

FIG. 4. SEM micrograph of transition wood (arrow). Note that the tracheids had wide fiber diameters characteristic of normal earlywood, but thicker cell walls. Note also the 5–6-sided cells typical of Japanese larch tracheids (115×).

with the formation of transition wood (Larson 1972). Transition wood, defined as intermediate-type tracheids that lie between the earlywood and latewood in the ring, occurs frequently in juvenile wood and in fast-grown rings of older trees (Larson 1973). These tracheids are neither earlywood nor latewood, although they have characteristics of both (Larson 1972). This wood usually has specific gravity higher than normal earlywood, but lower than normal latewood. The specific gravity of fast-grown wood often reflects the width of the transition wood zone rather than the width of either the earlywood or latewood (Larson 1973). Acceleration of growth (e.g. fertilization) results in a broader transition wood zone and thus more uniform structure within rings (Larson 1972).

A large portion of the juvenile annual rings in our trees was transition wood. This can be illustrated by ring '67 and '68 of the X-ray densitometer trace in Fig. 2. Note the decrease in specific gravity and increase in within-ring uniformity that characterizes the wide transition wood zone. Anatomical features of the tracheids of this wood resemble earlywood more than latewood. They have large fiber diameters characteristic of normal earlywood, but thicker cell walls (arrow, Fig. 4).[5] Figure 4 also shows the accentuated 5–6-sided cell shape characteristic of Japanese larch (Greguss 1955).

Latewood percent

Latewood percent is a commonly measured wood property in conifers because it is highly correlated with specific gravity (Langner and Reck 1966) and is related to certain paper properties.

Juvenile wood in conifers is an arbitrary term used to describe wood produced by the growth rings near the pith. The width of the juvenile zone varies with species and is usually determined by plotting anatomical, physical, and chemical properties across series of annual rings. Silvicultural practices such as cultivation, fertilization, and irrigation often modify the age curve of wood properties in conifers through their influence on the crown, which extends the juvenile period (Larson 1972). Latewood percent is normally low in juvenile wood irrespective of growth rate, so an extension of the juvenile period in larch would no doubt increase the likelihood of low latewood percentages. Unfortunately, the width of juvenile wood zone has not been sufficiently established in Japanese larch.

Greguss (1955) points out that Japanese larch wood is usually low in latewood percent. Although latewood percent ranged widely within our trees from 1.6 to 20.4%, it was generally low in all rings except for the outermost growth sheath (Table 3). The within-tree trends of latewood percent were similar among all our sample trees; Table 3 illustrates these trends although it represents but one tree. Note the general increase from pith to bark at all sampling heights, with very low latewood percent in the first few rings from the pith.

If latewood percent is used to define juvenile wood, the low latewood percent pres-

[5] The authors wish to acknowledge the cooperation of Dr. R. A. Parham, Institute of Paper Chemistry, Appleton, WI. on the SEM micrographs.

TABLE 3. *Latewood percent within an individual rapid-grown Japanese larch tree. Sampling positions conform to those shown in Fig. 1*

Sampling height	Latewood percent (%)														
4	10.62	3.50	4.03	2.00								2.33	3.16	4.09	8.32
3	10.79	5.83	3.45	8.20	2.43						1.60	6.45	4.63	9.76	17.96
2	12.95	10.44	9.90	5.22	1.60	5.86				5.86	2.61	6.24	6.84	8.18	15.05
1	11.68	4.50	8.56	6.87	4.04	4.04	6.05	8.87	4.47	3.85	3.08	2.41	6.20	4.52	12.65
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	B_7	B_6	B_5	B_4	B_3	B_2	B_1
Bark								Pith							Bark
	Annual growth sheath increment number														

ent indicates that the juvenile period may last at least 10 years in rapid-grown Japanese larch.

In the outer rings (age 10) latewood percentages range from 10–18%, but this is still well below the 18–21% in the juvenile wood of plantation-grown Japanese larch and the 22–30% in juvenile wood of European larch found by Pearson and Fielding (1961). Apparently the low latewood percent in our wood is related to the full vigorous crown commonly found in stands under intensive silvicultural treatment (Nicholls et al. 1974). It should be emphasized that wood with lower latewood percent is desirable for many paper products that require good collapsibility for fiber bonding, so the low latewood percent is not necessarily a negative attribute.

Incidence of compression wood and compression wood anatomy

Compression wood percent is an important factor in the utilization of juvenile wood because it lowers pulp yields. In our trees the incidence of compression wood was almost exclusively associated with the latewood portion of almost every annual ring. Since we have shown that latewood percent is only a small portion of the annual ring in these trees, the total amount of compression wood was low. The incidence of compression wood was highest in the upper parts of the tree and in the older annual rings as shown by the profile in Fig. 3. We believe the high incidence of compression wood found in these trees is related to the rapid growth rate in the juvenile period. Juvenile wood and rapid-grown wood often have high amounts of compression wood (Zobel et al. 1971; Zobel and Kellison 1972).

The structure of the Japanese larch compression wood was similar to that reported by Côté and Day (1965) and Scurfield and Silva (1969). The compression wood tracheids were round and had distinct intercellular spaces. Furthermore, the inner cell walls were characterized by typical helical checks and distinct ridges (Fig. 5).

Percent of extractives

Extractive percent is one of the most important wood properties with respect to the utilization of larch wood for pulp because of the effect extractives have on pulping. With this in mind, we were particularly interested in the effect of rapid growth on extractive content. The distribution of extractives in conifers is related to heartwood formation, which in turn is a function of both age and growth rate (Hillis 1971).

Larch wood is generally known to be high in extractive content (Côté et al. 1966). Hakkila et al. (1972) and Hakkila and Winter (1973) found that the amount of hot water extractives alone ranged from 8–12% in Siberian larch, depending upon position sampled. Packman (1966) reported that extractives from mature Japanese larch wood (age 15–24) amounted to 7.7%. By comparison, juvenile larch wood has a lower extractive content because it

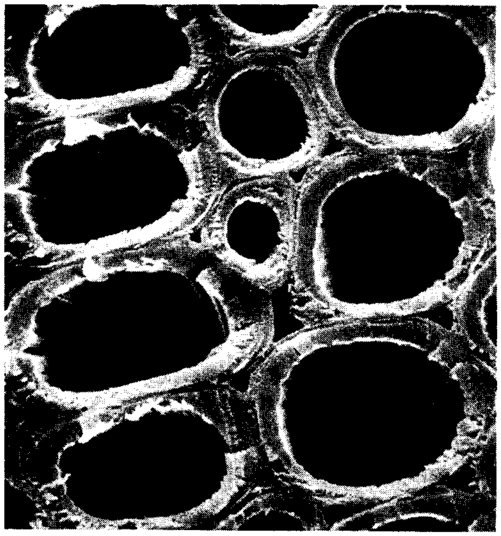

FIG. 5. SEM micrograph of compression wood tracheids with distinct rounded shape and numerous intercellular spaces. Note the helical checks and ridges on the inner cell walls (1150×).

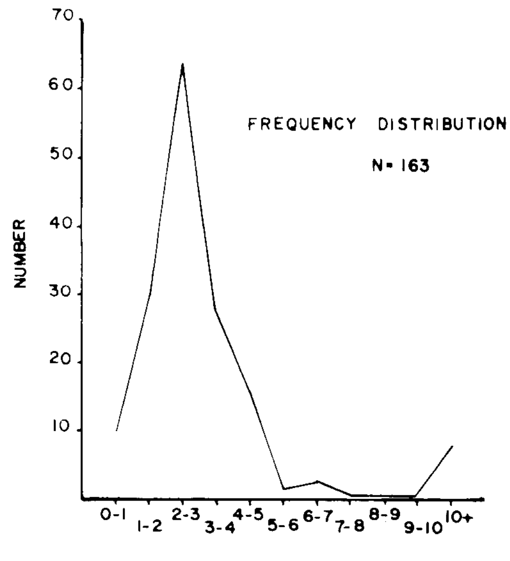

FIG. 6. Frequency distribution of the extractive percents of all samples collected for the Japanese larch trees (n = 163).

consists mostly of sapwood (Uprichard 1963; Hakkila et al. 1972).

Extractive contents ranged from 0.6–23.9% within trees; however, they ranged only between 2.0–6.0% in most rings (Fig. 6). They were low at all positions except in the central core of the base, where higher percentages were observed. This likely reflects the onset of heartwood formation, which Hirai (1952) has reported occurs first in Japanese larch at age 5 at the core of the base. The higher extractive content found at the central part of the base would also influence specific gravity; specific gravities were higher at the pith than expected.

If the onset of heartwood formation was used as an index of the transition from juvenile to mature wood, our data suggest that the juvenile period would be approximately 10 yr. The intensive silvicultural practices used in the study stand may have prolonged the juvenile period which could have delayed heartwood formation, which according to Hillis (1971) would account for the low extractive percent. Klemm (1967) also concluded that fertilization of several conifers decreased the percent of extractives because it increased the amount of sapwood. It should be emphasized that the problem of high extractive contents influencing the utilization of larch wood can be partially solved by the use of younger trees with a high proportion of sapwood (Jeffers and Isebrands 1974), such as those in this study.

BARK PROPERTIES

Recent emphasis on utilization of whole trees has prompted more interest in bark. In this study bark percentages ranged from 14.0–21.3% (weight basis), depending upon position in the tree. They increased dramatically from the base of the tree to the top as was also observed by Hakkila and Winter (1973) in Siberian larch. Although bark thickness decreased from 0.73 cm at the base to 0.10 cm at the uppermost sampling height, the bark/wood ratio (ovendry weight basis) increased with height from 0.16 to 0.27, because of the smaller diameter at the top (Table 4).

Increased growth and maturity of trees normally result in lower bark percentages, because of increased wood volume and loss of bark. However, Hakkila et al. (1972)

TABLE 4. *Bark thickness (cm), bark/wood ratio (oven-dry weight basis), and bark percentage of 9-yr-old Japanese larch trees at 5 heights in the stem*

Segment #	Bark Thickness[a] (cm)	Bark/wood ratio[b] (oven-dry wt. basis)	Bark %
5 (top)	0.10 ± 0.00[c]	0.27 ± 0.04[c]	21.3
4	0.48 ± 0.07	0.23 ± 0.04	18.9
3	0.58 ± 0.06	0.20 ± 0.03	14.7
2	0.62 ± 0.06	0.16 ± 0.02	14.2
1 (base)	0.73 ± 0.08	0.16 ± 0.03	14.0

[a] n = 12 [c] Mean ± 95% confidence interval

[b] n = 6

reported that bark percentage in mature Japanese larch (age 50) averaged 12.3% (weight basis) as compared to 12–14% for other larch species, and, Nevalainen and Hosia (1969) reported bark percentage ranged as high as 19% (volume basis) for 31-yr-old Siberian larch.

We believe that our trees have a low bark proportion for their age, attributable to intensive management (i.e. fertilization and irrigation). More research on bark composition of Japanese larch for complete tree use is necessary.

TREE IMPROVEMENT POSSIBILITIES

In selecting and breeding of conifers, primary emphasis is placed on improving growth rate and tree form with wood uniformity and volume production also of upmost importance; selection for superior wood quality characteristics is usually secondary (Zobel and Kellison 1973). Therefore, one should first select for growth rate and form, and then select within this group for desirable wood properties (Smith 1967) as determined by the final product.

One of the most comprehensive conifer tree improvement programs has been carried out on southern pines. The most important wood characteristic to be selected for is specific gravity, largely because mean progeny values for specific gravity serve as predictors of specific gravity at older ages (Stonecypher and Zobel 1966; Matziris and Zobel 1973).

We believe that the same type of tree improvement program can also be used to improve Japanese larch. Top priority should be given to selection of trees having superior growth rates and forms, possible because of the wide range of variability of these characteristics in our material. Within these selections, one should then screen for specific gravity depending upon the desired product. Although all trees we studied had acceptable specific gravity, improvement of this characteristic seems possible because several trees we investigated had higher juvenile wood specific gravities than others. If we assume that Japanese larch trees follow the usual pattern of increasing specific gravity with age, trees of high juvenile wood specific gravity should maintain high specific gravity throughout their life. Furthermore, when pulp fiber is the desired product, improving specific gravity will also result in increased pulp yield (Zobel et al. 1971).

Because extractive content is an important factor in utilization of larch for pulp, the possibilities for selecting trees having delayed heartwood formation should be investigated further. If this is possible as Hillis (1971) suggests, extractive content might also be controlled.

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