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Growth of European Larch at Five Spacings

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Restrictive economic conditions and increased knowledge have led foresters to question traditional spacing of forest trees and to conduct research that would test their assumptions. Numerous studies have confirmed that when forest trees are widely spaced, the branches, crowns, and stems are larger. Although the stem form of all trees is changed, the height of conifers may be little affected. An immediate economic benefit is derived from lower planting and precommercial thinning costs. Later, although early stand basal area and volume growth may be reduced by wide spacing, more rapid growth of individual stems can produce more merchantable volume, a shorter rotation, reduced logging costs, and better financial returns.

Determining an initial spacing for plantations is an investment decision. In earlier times, close spacing was appropriate when labor costs were low and markets existed for small stems cut from crowded stands. But sharp rises in planting and precommercial thinning costs and forecasts of better financial returns from larger stems have spurred an interest in wider spacing. However, upper limits of spacing are usually determined by their effects on tree quality. There must be enough trees from which to select an adequate number of high-quality stems for lumber, poles, or other products. Moreover, widely spaced trees have large branches that cause large knots, delay natural pruning, and increase the cost of artificial pruning. The effects on ring growth and taper changes are variable and less well understood.

A comprehensive literature review of these and other considerations of initial spacing has been made by Evert (4). Although general information on spacing effects is available, more exact physical data are needed for different species, sites, and management goals. This paper presents 25-year growth data for European larch *(Larix decidua)*. It is particularly valuable because an unusually wide range of spacings were tested.

The Experiment

European larch was planted in mid-April 1950 on Cornell's Arnot Forest at measured spacings of 6.6′ × 6.6′ 8′ × 8, 10′ × 10′, 16′ × 10′, and 14′ × 14′ (fig. 1). Later measurement showed that the actual spacing corresponded closely to the designed spacing (table 1). Good 2-0 stock was planted by the mattock slit method on old-field stony Lordstown soils at an elevation of 1800 feet. Such soils, if sufficiently deep and moist, are among the better ones in southern New York for growing larch (1). Specific source of the seed is unknown — only that it came from Austria[1]. Judging from the generally good growth of the past 25 years, it was one of the better seed sources then available.

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[1]Personal communication with David B. Cook, then with the State of New York Conservation Dept., letter of 5/25/62.

 

Figure 1. *Crowded crowns of 25-year-old European larch with 6.6′ × 6.6′ spacing (left) and open crowns with 14′ × 14′ spacing (right). In the absence of thinning, the wide spacing is superior.*

Table 1. *Trees planted per acre, designed and actual*

Spacing	*Designed*	*Actual*
feet	*number*	
6.6 × 6.6	1000	1005
8 × 8	681	670
10 × 10	436	433
16 × 10	272	271
14 × 14	222	216

The trees were planted in two small fields, each of which appeared to have near-uniform growth potential. The east field had deep, quite stony soil, and hardwoods were starting to invade. The west field had somewhat more shallow soil with fewer stones and no hardwoods. Five one-third-acre plots, one for each spacing, were located in each field. The plots were adjacent and located clinally, from the 6.6′ × 6.6′ to the 14′ × 14′ spacing, to minimize effects of aspect or exposure. This clinal orientation also minimized the edge effect between spacings, thus saving space and permitting the use of the most uniform portions of the field. The same work crew made all the plantings within a three-day period. Thus all spacings had similar plants, uniform methods, and near-equal sites.

Small amounts of invading hardwoods that competed in the upper crown level were removed 10 and 25 years after the larches were planted. Some 110 to 140 of the largest and best larches per acre were selected for crop trees at age 12 and were pruned to a height of 9 feet for ease of identification. At the same time, a few of the nearest competing larch (about 90 per acre) were chemi-thinned in the 6.6′ × 6.6′ spacing. This was the only thinning among the larch and, although very light (about 6 sq. ft. per acre), it may have increased the size of the crop trees a small amount. In addition, crowding caused 4 square feet of mortality. Thus, on a stand basis, the thinning may simply have forestalled a larger mortality. In further references to mortality, this thinning is included as mortality; thus the mortality is considered to total 10 square feet for the 6.6′ × 6.6′ spacing.

Management after planting, then, has been principally reducing hardwood weed competition and selecting crop trees. The principal environmental factors known to affect growth have been drought and larch sawfly. Fortunately 1950 was a good growing season to get the young seedlings started and the weather remained near normal for most of the first decade. The 1960s were dry, especially a 5-year period of very dry summers in the period 1962–66.[2] However, larch continued to grow well, possibly because there was more rainfall at the high elevation. After the 1969 growing season, growth slowed sharply in all spacings — a condition that coincided with partial defoliation from the larch sawfly in the 1969–72 period. Since crowding and defoliation concurrently decreased radial growth for a period of time, it is difficult to determine just when crowding became critical in each of the spacings.

Because some trees or spacings were unequally exposed to competition in addition to that from spacing, portions of the plots were not included in growth analyses. Outer rows of the experiment, usually two or more, were excluded, as were areas with above-average initial hardwood invasion. Final plot sizes ranged from .15 to .30 acre.

All tree diameters (outside bark) were measured at breast height (4.5 ft.) in late July 1964 and June 1975. The current season's growth was deducted from the 1975 measures to obtain 25-year growth data. Although the 1964 measurements preceded the end of the fifteenth growing season, they are used as 15-year data. Since most of the larch reached breast height in 4 years, the

[2]Weather records from Caldwell Field, Ithaca.

mean growth data for the following approximate 11- and 10-year periods were obtained from these diameter measures.

To test significance of the data, each spacing plot was subdivided into numerous subplots of about .01 to .02 acre. In the closest spacing, a subplot was approximately 20′ × 20′ or the equivalent of 9 trees (3 each direction). For the widest spacing, a subplot was 28′ × 28′ (4 trees). These subplots furnished ample data for analyzing growth differences between plots, but are no guarantee against possible site bias. Site uniformity was sought through careful selection, use of relatively small plots, and clinal orientation[3].

Breast height measures are insufficient because growth varies throughout the tree. Therefore the most typical subplot, as determined by mean diameter growth, was selected for each spacing in each field. All trees were cut and measured for total height and crown depth. The largest three (occasionally only two) tree stems were analyzed at heights of 4.5 (BH), 9, 17, 25, and 33 feet to obtain data on radial growth and stem form. Since so few plots were involved, no statistical analysis was made for radial growth, stem form, tree height, or crown depth.

Branch diameters were measured and estimates of tree quality were made on individual trees, whereas each plot was observed for litter depth and ground cover.

Survival and Mortality

Initial survival averaged 90 percent in the more stony field and 93 percent in the other. There was no significant difference between spacing plots.

Mortality, which occurred mostly in the last decade, ranged from 10 square feet per acre in the 6.6′ × 6.6′ spacing, to 2 square feet per acre in the 8′ × 8′ spacing, to virtually nothing in the wider spacings.

After 25 growing seasons, the number of larch stems per acre for the 6.6′ × 6.6′, 8′ × 8′, 10′ × 10′, 16′ × 10′, and 14′ × 14′ spacings was approximately 720, 570, 390, 250, and 200, respectively (72, 85, 90, 92, 93 percent of the original number). In the absence of thinning, additional mortality can be expected to continue to substantially reduce the number of stems in the closer spacings.

Height

Mean height of the 100 tallest trees per acre after 25 growing seasons was approximately 49 or 50 feet in all but one plot. It was only 45 feet in one of the 10′ × 10′

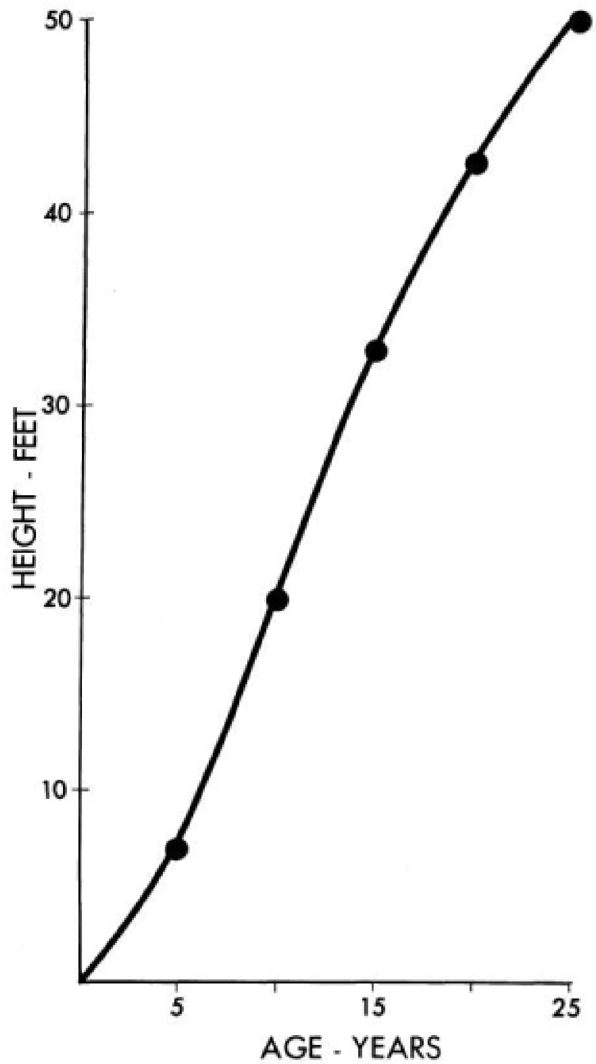

Figure 2. *Height-age curve of European larch, based on the 100 tallest trees per acre.*

plots, possibly because the soil was shallower. There was a slight tendency for the closer spacings to have the tallest 100 trees per acre. This is to be expected since there are more trees per acre[4].

Figure 2 is a height-age curve made from stem analysis data taken from the 6.6′ × 6.6′ and 8′ × 8′ plots. It follows closely the Site II curve of Aird and Stone (1), with a slight decline in the last five years. The single tallest tree grew according to their Site I curve.

Crown Depth

In 1964 when the trees were a little over 30 feet tall, the estimated average crown depth of the crop trees varied from 19 feet to about 22 feet for the closest and

[3]An alternative is numerous small randomized plots, which require more surround trees, more area, and much more expense.

[4]When selecting a discrete number of either largest or smallest trees, more divergence from the mean is expected in higher populations (close spacings).

Table 2. *Mean crown depth at age 25*

Spacing	Largest trees (half basal area)	All trees
	feet	
6.6 × 6.6	20	18
8 × 8	21	19
10 × 10	22	20
14 × 14	28	27

widest spacings. Crown width varied much more as the trees extended their branches to utilize the site.

After crown closure, crown depth tended to become constant although crown width and volume varied directly with the spacing (fig. 1). Table 2 shows approximate mean crown depths (at age 25) for the larger trees, which contain half the stand basal area, and for all the trees in the upper crown level. Only trees in the 14' X 14' spacing, just recently closed, had notably deep crowns. Although crowns of wide-spaced trees are indeed massive for a time (figs. 3 and 4), the intolerant European larch apparently tends to approach a constant crown depth of about 20 feet after the crowns close. This characteristic is similar to that of red pine, another intolerant (6). As a consequence, live crown ratio can be a very poor and deceiving indicator of vigor.

Diameter Growth at Breast Height

Breast height was usually reached after 4 growing seasons. All trees were measured (Dbh o.b.) near the end of 15, and after 25, growing seasons. The mean diameter

Figure 3. *Exceptionally large crown of 25-year-old tree in 14′ × 14′ spacing. A missing tree on one side promoted more growth.*

Figure 4. *Massive crown of largest tree cut from 14′ × 14′ spacing at age 25.*

Table 3. *Mean diameter growth*

Spacing	All trees			Crop trees		
	11 years	*10 years*	*21 years*	*11 years*	*10 years*	*21 years*
feet	*inches*			*inches*		
6.6 × 6.6	4.3	1.5	5.8	5.4	2.2	7.6
8 × 8	4.8	1.7	6.5	5.8	2.2	8.0
10 × 10	5.3	2.0	7.3	6.1	2.4	8.5
16 × 10	5.6	2.5	8.1	6.1	2.7	8.8
14 × 14	5.8	2.9	8.7	6.2	3.0	9.2

growths for approximate 11- and 10-year periods after reaching breast height, are shown in table 3. It also shows the sum or total diameter growth for 21 years (25 growing seasons after planting).

With one exception[5], the 21-year mean diameter growth (all trees), was significantly different (95% level) for each spacing. Growth differences were also substantial, with the most widely spaced trees averaging about 3 inches thicker than those closest together.

Because they were usually the larger trees (with bigger crowns) at an early age, the crop trees were vigorous and continued to outgrow surrounding trees in all spacings. This was particularly true in the closer spacings; consequently growth differences between crop trees at different spacings were less than those for surrounding trees. This suggests that the more dominant of the intolerant larches, even in crowded stands, can I grow well for a time. Early thinning to give selected individual trees room for crown development should effectively stimulate stem growth.

Basal Area Growth

Stand basal area growth[6] of larch was greatly influenced by spacing in early life (table 4). After 11 years (15 growing seasons after planting), the basal area of the 6.6' x 6.6' spacing was double that of the 14' x 14' spacing. But basal area growth differences were much

Table 4. *Stand basal area growth*

Spacing	Basal area growth			Mortality	Net growth
	11 years	*10 years*	*21 years*		
feet	*square feet per acre*				
6.6 × 6.6	80	57*	137	10	127
8 × 8	74	57*	131	2	129
10 × 10	59	55*	114	0	114
16 × 10	44	45	89	0	89
14 × 14	39	46	85	0	85

**Basal area increment is very close to data calculated from British yield tables (7) for similar sites and same age.*

[5]16′ × 10′ spacing not significantly different from 14′ × 14′ spacing.
[6]Combined growth of all trees in cross-sectional area at breast height, including bark.

Table 5. *Basal area growth, crop trees*

Spacing	*11 years*	*10 years*	*21 years*
feet	*square feet per acre*		
6.6 × 6.6	20	20	40
8 × 8	23	21	44
10 × 10	25	24	49
16 × 10	26	27	53
14 × 14	26	32	58

less during the following decade as more stands became closed. Even trees in the 10′ × 10′ plantings appear to have occupied most of the growing space as early as a dozen years after reaching breast height. Since all stands are now virtually closed, no major differences are foreseen between spacings in future stand basal area growth.

Basal area growth of crop trees, unlike total stand growth, increased with wide spacing (table 5). For comparison, data are adjusted to an average of 125 crop trees per acre. In comparing tables 4 and 5, note that two-thirds of the stand basal area in the 14′ × 14′ spacing was in crop trees at age 25 (58 of 85 sq. ft.), compared to about a third in the 6.6′ × 6.6′ and 8′ × 8′ spacings. Since basal area is approximately proportional to volume in stands of equal height, wide spacing can greatly increase the volume of selected crop trees. If stands are not thinned, this effect magnifies with time.

Radial Growth — Upper Stem

Radial growth in trees varies with time and stress, as well as with location within the tree. Table 6 shows mean annual ring growth of crop trees, by age periods, for heights likely to be of commercial interest. As expected, growth was faster where associated with youth. It decreased from the pith outward and from the upper stem downward to a height of 9 feet or lower. These normal growth trends were influenced by spacing; more occurred with wider spacing.

The variation in growth rates for this intolerant species is striking. Some rings were more than four times wider than others. Radial growth begins as rapid juvenile growth and, within a very few years, declines to an extremely slow rate unless the stand is thinned. This variation affects both volume and wood quality.

Rapid radial growth is desirable for making tree-farming financially worthwhile, but too-rapid growth of conifers can reduce specific gravity, strength, or other aspects of wood quality. However, uniformity of growth is usually more important than rate of growth in its effect on quality. Consequently, ring widths from .20 to .08 inch (5 to 12.5 rings/in.) have been selected to illustrate a range of suitable growth rates.

Table 6 and figures 5 and 6 show that larch growth did not remain long at the selected range of growth rates in

Table 6. *Mean annual ring width for crop trees, by 5-year periods, at fixed heights*

Height (ft.)	6.6′ × 6.6′ spacing 10–15*	15–20	20–25	8′ × 8′ spacing 10–15	15–20	20–25	10′ × 10′ spacing 10–15	15–20	20–25	14′ × 14′ spacing 10–15	15–20	20–25
BH	**.17†**	**.12**	.06	**.18**	**.12**	.06	.24	**.14**	.06	.24	**.16**	**.08**
9	.21	**.12**	.06	.23	**.13**	.06	.27	**.14**	.06	.27	**.18**	**.09**
17	.27	**.15**	.07	.27	**.16**	.07	.27	**.20**	**.08**	.27	.23	**.11**
25		.21	**.09**		.23	**.09**		.26	**.10**		.26	**.14**
33			**.12**			**.14**			**.14**			**.14**

**Age in years.*
†Ring width in inches.
Lines and italic type delineate ring widths between .20 and .08 inch (5 and 12.5 rings/in.).

the absence of thinning. A narrow band of suitable growth, often only an inch wide, moved up the tree with time. As with red pine (5), specific growth rates are not easily attained over much of the tree bole. These intolerant species, extra-sensitive to the effects of stand closure and crowding, apparently need carefully timed and continuous thinnings to control stand density, although there are limits to what can be accomplished.

Initial spacing has much less effect on radial growth than commonly supposed, provided it is followed by a suitable thinning program. It directly influences the amount of very rapid juvenile growth (fig. 6). Following crown closure, however, growth quickly slows in all spacings. After 25 years there was little difference between the 6.6′ × 6.6′ and 8′ × 8′ spacings; thinning in each was overdue by at least 10 years. Trees in wider spacings grew bigger but also became crowded. The 10′ × 10′ spacing should have been thinned at about age 20, and the 14′ × 14′ spacing at age 25 or shortly after to provide continued good growth at breast height. The principal effects of initial spacing, then, are on the timing and cost of the first thinning and the size of the core of juvenile wood.

The rapid growth and relatively light weight of juvenile wood cause technical problems in the use of wood, often reducing quality and sometimes yield. This has deterred adoption of wider spacings. However, not all factors were well analyzed. Concern about juvenile growth may have been overemphasized for the following reasons:

- The juvenile core makes up only a small fraction of the tree volume, except in very short rotations.

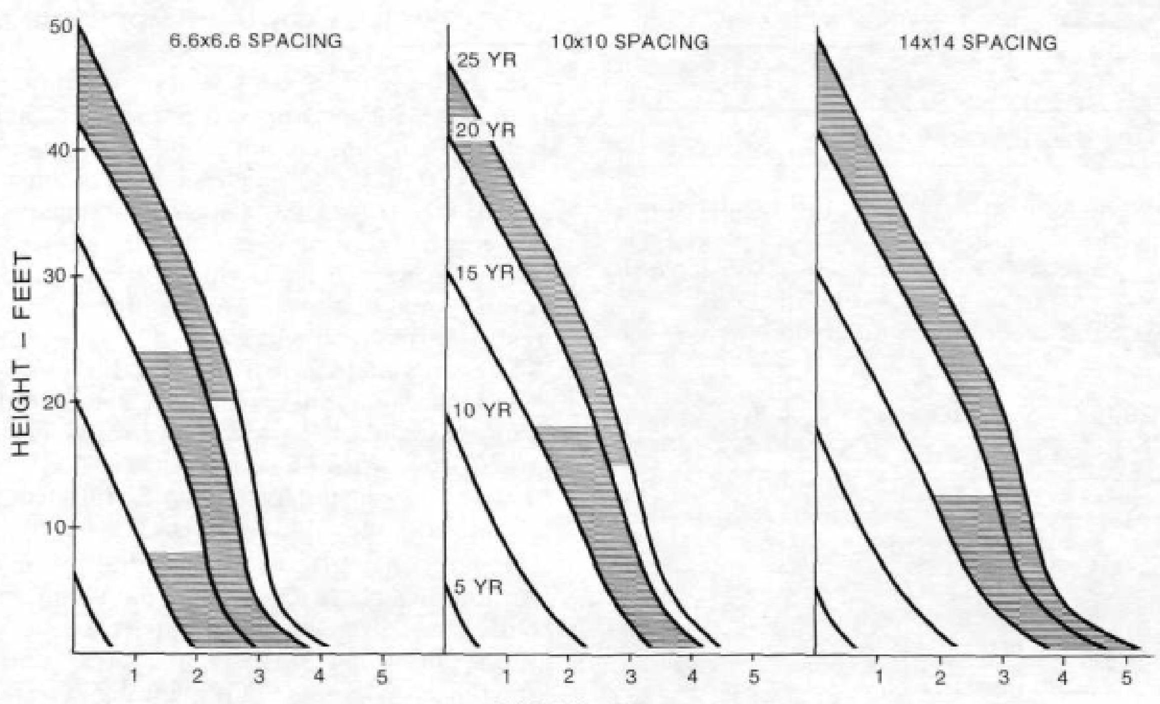

Figure 5. *Mean periodic (5-year) growth of crop trees at 3 spacings. Growth at 8′ × 8′ differed little from that at 6.6′ × 6.6′ and is omitted. Mean growth rates between 5 and 12.5 rings/in. indicated by darkened areas. These growth rates were restricted in location, often in wood less than 1″ wide at various heights.*

- There is probably little difference between spacings in the amount of juvenile wood per acre. In closely spaced plantations there are many more, although smaller, juvenile cores. Some portion of the additional early volume production in close spacings is in the form of juvenile wood.
- When a tree has a larger-than-average juvenile core, it develops more mature wood, there being a greater circumference on which mature wood can grow. This effect is repeated with each successive annual ring in the process of tree growth. It is magnified in the absence of thinning, when closely spaced trees suffer longer and more extremely from stagnation. Even when closely spaced trees are thinned, a substantial amount of mature wood is removed from the stand and often underutilized.
- Intolerant species, such as European larch, inherently have an early rapid growth that slows all too soon[7]. Large cores of juvenile wood, formed quickly on relatively few trees per acre (wide spacing), provide the bases needed for use of early, rapid basal area increment to form more mature wood per tree with suitable growth rates[8]. To reduce juvenile growth by close spacing is to waste some of the best growth potential of the tree; it is a loss that later thinning cannot repair.
- Modern wood-use technology offers the means to subdivide trees and make the best use of both mature and juvenile wood.

Juvenile wood can be an asset then as well as a liability. Most forests have an ample supply of slow growth; too-rapid growth, by comparison, is of much less concern.

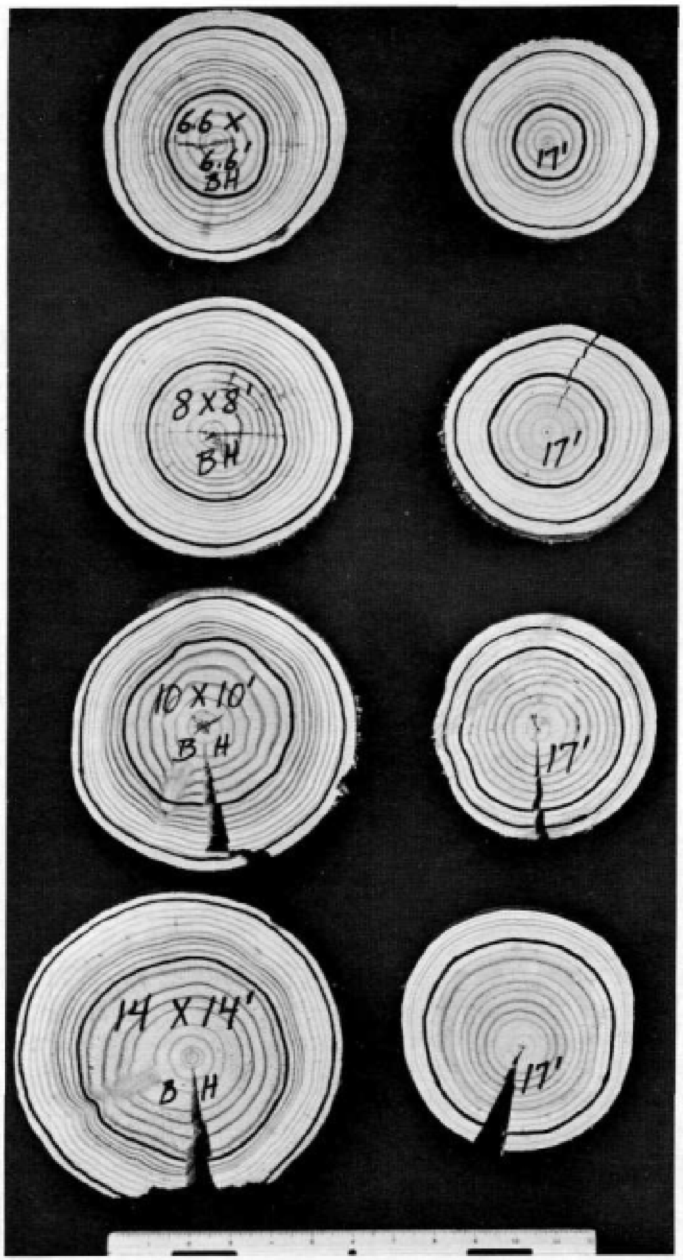

Figure 6. *Variation in growth rates for 4 sample trees at different spacings (6.6′ × 6.6′ to 14′ × 14′) and 2 heights (BH and 17 ft). Dark circles enclose the area of growth between 5 and 12.5 rings/in.* **Note:** *These samples do not necessarily represent average growth.*

Stem Form

Stem form and taper are determined by changes in radial growth. Therefore the effects of initial spacing on stem form tend to be transitory. On the basis of relatively few measures, form classes[9] at age 25 for the 6.6′ × 6.6′, 8′ × 8′, 10′ × 10′, and 14′ × 14′ spacings were established at approximately 66, 64, 62, and 60, respectively. As expected, form class was lower in the more open stands. As these stands age and close, form class will increase, and differences can be expected to diminish and possibly disappear.

Branch Diameter — Pruning

Wide spacing encourages longer and thicker branches, which contribute to greater stem growth. Consequently, branch diameter is related to both spacing and stem diameter. Moreover, crown closure is delayed in wide spacings and the lower branches persist longer. Table 7 shows some relationships between branch diameter and spacing at age 25.

[7]See tables 3 and 4. Table 3 shows greatly reduced diameter growth in the last decade, even at 14′ × 14′. Table 4 shows reduced basal area increment in the last decade.

[8]See table 6 and figure 5. At age 25, there was little difference between spacings in the *width* of radial growth within the selected limits of 5 and 12.5 rings/in. However, wider spacings had more such growth because circumferences were larger.

[9]Form class is ratio of diameter at half-height above breast height to diameter at breast height. Inside bark diameters were used.

Table 7. *Mean diameter of largest branch* at 2 locations*

Spacing	Dead branches at height 3 - 7 feet	Live branches: lower live crown
feet	*inches*	*inches*
6.6 × 6.6	.62	.9
8 × 8	.75	1.0
10 × 10	.88	1.1
16 × 10	1.12	1.2
14 × 14	1.20	1.3

**Largest branch from each locality in each tree measured at base.*

Table 8. *Number of potential pole trees per acre at age 25*

Spacing	All trees		Excluded trees		Potential poles	
	Crop	Filler	Crop	Filler	Crop	Filler
6.6′ × 6.6′	130	590	20	110	110	480
8′ × 8′	110	460	10	70	100	390
10′ × 10′	115	275	15	55	100	220
16′ × 10′	130	120	20	15	110	105
14′ × 14′	120	80	15	35	105	45

Except for the two widest spacings, there was a significant difference between spacings in the size of the lower dead branches. Branches at the 14′ × 14′ spacing were twice as thick as those at the 6.6′ × 6.6′ spacing, and they had nearly four times the cross-sectional area. This large difference is attributable both to the additional space and to the longer lifetime of the lower branches in the widest spacing.

In the lower live crown, which contains many of the larger tree branches, there was a smaller difference in branch diameters with spacing, since all branches were alive and growing. Maximum branch size commonly seen in the plantings varied usually from slightly over 1 inch to a little more than 2 inches for the 6.6′ × 6.6′ and 14′ × 14′ spacings, respectively.

It is apparent that pruning crop trees in a 14′ × 14′ spacing may require double the energy or more in comparison with a 6.6′ × 6.6′ spacing[10]. However, suitable mechanical methods could reduce time and dollar costs. Early live pruning in wide spacings can also reduce costs but at the expense of some epicormic branching. Even so, there will be some larger knots remaining in wood products, especially from upper stems.

Tree Quality and Use

Perhaps of most concern are the effects of initial spacing on tree quality and various end uses. Are there enough good trees of sufficient size to provide the desired lumber, poles, pulp, or other products?

For lumber production, up to 150 stems per acre are commonly selected as crop trees. All the tested spacings supplied at least that many good stems for this purpose — an ample number of sawlog trees for high-quality lumber production under most circumstances.

Pole specifications are more requiring than sawlog needs. The Pole Grower's Guide[11] was used to estimate the numbers of potential[12] pole trees per acre for various spacings (table 8). These were subdivided by crop and noncrop, or filler, trees. Potential pole trees were those remaining after trees with basal crook (5-10%), excessive sweep (5%), and crook, lean, or forking (5%) were excluded. The table may be misleading because it includes many small, slow-growing trees in close spacings, and it may include some trees with excessive taper in the widest spacing. In addition, pruning may be needed in the wider spacings to control knot sizes. In general, table 8 suggests an ample potential for growing poles at 10′ × 10′ or closer spacing; the potential decreases at wider spacings.

The most serious consequences of initial spacing of larch appear to be related to size rather than quality of stems. At close spacings, early thinnings are needed to promote continued, vigorous diameter growth. But many stems are too small to have enough value to pay for their removal. Thus, costly precommercial thinnings may be needed. Table 9 shows some relationships between tree size and initial spacing at two ages.

Larch stands planted at 6.6′ × 6.6′ or 8′ × 8′ need thinning at age 15 or before for *continued* good diameter growth (table 6, figs. 5 and 6). But virtually all of the noncrop trees are less than 6 inches in diameter. In many cases, a commercial thinning (where value of extracted wood exceeds thinning costs) could not be made before age 25 — at least 10 years too late.

Larch planted at 10′ × 10′ needs thinning at about age 20. Table 9 suggests that a commercial thinning may be feasible, but it does not account for the fact that many of the larger trees are crop trees. Table 10 shows numbers and basal areas of noncrop or filler trees at age 20. If 6-inch trees are merchantable, there are enough (basal area, 40 sq. ft./acre) for a commercial thinning. But if 7-inch trees are required, there may be too few (only 20-25 sq. ft.) for a commercial operation.

Larch planted at 14′ × 14′ needs thinning at age 25 or shortly after. While individual trees are large enough, there aren't enough of them. Tables 4 and 5 indicate a net growth of 85 square feet per acre at age 25; 58 square feet is in crop trees, and only 27 square feet is available for thinning.

[10]Cost differential was less in pruning crop trees to 9 feet high at age 12. Time for pruning trees with a Mehlan saw averaged 5.6, 6.0, and 7.4 min./tree for the 6.6′ × 6.6′, 10′ × 10′, and 14′ × 14′ spacings, respectively. Relative costs probably increase for later pruning.

[11]Southern Forest Experiment Station. Occasional Paper 153. 1957. H. L. Williston.

[12]If suitable thinning, pruning, and other silvicultural needs are provided for growing them into poles.

Table 9. *Numbers of trees per acre that exceed specified diameters, at 2 ages*

Spacing	Diameter (BH) 6 inches 15 years		6 inches 25 years		8 inches 25 years		10 inches 25 years	
6.6′ × 6.6′	25	(<5)*	260	(35)	40	(5)	0	
8′ × 8′	60	(10)	340	(60)	70	(10)	0	
10′ × 10′	90	(20)	300	(75)	120	(30)	5	
16′ × 10′	95	(40)	220	(90)	120	(50)	5	
14′ × 14′	90	(45)	200	(100)	140	(70)	30	(15)

*Numbers in parentheses are approximate percentages of total trees per acre.

Table 10. *Numbers of trees and basal areas per acre that exceed specified diameters, noncrop trees in 10′ × 10′ spacing, age 20*

Diameter	Number of trees	Basal area
inches		*sq. ft.*
6	150	40
7	75	20–25
8	10	<5

Of all those tested, the 10′ × 10′ initial spacing appears superior in many circumstances for promoting suitable growth of larch, economical thinnings, and production of a variety of wood products.

Ground Cover, Litter Depth, Invading Hardwoods

After 25 years there was substantial variation in ground cover and depth of forest litter. The latter averaged about three-fourths inch in the 6.6′ × 6.6′ and 8′ × 8′ spacings. It was about a half-inch in the widest spacings, presumably because crown closure required a longer time. Ground plants were generally absent (10% or less of area) under the two closest spacings, but covered about one-third of the area under the 10′ × 10′ spacing and about two-thirds of the area under the 14′ × 14′ spacing. Old field grasses continued to dominate the latter area, despite the accumulation of forest litter and nearly complete crown closure. These grasses are expected to generally disappear in the next decade or so.

Invading hardwoods, given a foothold, are not usually crowded out by larch. Cook (3) has stressed the importance of early and effective removal of hardwoods from larch plantations.

Growth of invading hardwoods was related both to numbers present at time of planting and to initial spacing (openness). Most of the competing hardwoods were removed 10 years after the planting, but many smaller hardwoods grew into openings to become part of the upper crown level. After five years (15 years after planting) these trees were small, averaging 2.7 inches in diameter with a basal area of 3 square feet per acre, and there was little difference between spacings. But they grew rapidly in the next decade to average 4.3 inches in diameter and 7 square feet per acre, and it was necessary to remove them. Growth was considerably more rapid in the two widest spacings, averaging about 6 more square feet per acre for the decade[13]. In contrast to planting in the relatively clean fields used, planting among many invading hardwoods could incur high weeding costs that increase with the width of spacing.

Rectangular Spacing

Planted trees can be arranged in a number of geometric patterns, of which the square is the oldest, most common, and perhaps least desirable. Cook (2) argued strongly for rectangular patterns and favored a 6′ × 10′ arrangement in preference to one 8 feet square. The former spacing, oriented according to topography and road systems, provided room for passage for equipment needed in thinning and other forest operations and caused insignificant changes in growth. For today's mechanized equipment, an 8′ × 12′ spacing is probably superior to one 10 feet square.

Distribution of Crop Trees

For most conifers, approximately 100 crop trees are wanted near the end of the rotation. Preferably they should be evenly distributed at intervals of about 20 feet. This objective can be readily obtained with most initially close spacings and careful consideration of spacing when selecting crop trees. For a 6.6′ × 6.6′ foot spacing, for example, 1 of every 9 trees (in a 3 by 3 tree group) can be selected for a crop tree, yielding a total of 111 trees spread quite uniformly over an acre. In a 10′ × 10′ spacing, one of every 4 trees can be selected, making a total of 109 trees per acre, planted an average of 20 feet apart.

[13]The cost of removal in the two widest spacings was double that of the two closest spacings; i.e., 4 vs. 2 man-hours per acre.

For wider spacings, it is more difficult and sometimes impossible to achieve near-uniform distribution of crop trees. In a 14′ × 14′ planting, for example, a tree that did not survive or was thinned out would leave an area of 28′ × 28′ without a tree, resulting in some unused growing space. For this reason alone, a 14′ × 14′ spacing is impractical. A rectangular spacing of 10′ × 18′ is more practical, since removal of half the trees in each row can leave a stand averaging 18′ by 20′.

The following initial spacings are examples of some that could be readily used to achieve near-equal distribution of 100-140 crop trees per acre (average spacing of 18-21 feet): 6.6′ × 6.6′, 6′ × 10′, 8′ × 10′, 10′ ×10′. 9′ × 11′, 8′ × 12′, and 10′ × 18′. This goal cannot be achieved with initial spacings of 12′ × 12′, 14′ × 14′, 16′ × 16′, and 12′ × 16′.

Discussion

It is becoming clear that, within limits, the effects of initial spacing on radial growth and stem form are principally transitory. Wide spacing simply delays the need for the first thinning by a few years. In doing so, however, it can reduce the cost and increase the value of products therefrom. More permanent effects of wide spacing are lower planting costs and shorter rotations. These are partially offset by the costs of larger branches and knots.

The initial spacing can vary to accommodate objectives of land owners, particularly with respect to the products or satisfactions desired, species characteristics, and site productivity. For European larch, an initial stand of 400 trees per acre satisfies many financial objectives. This number can be obtained from a 10′×10′ or, even better, an 11′ × 9′ or 12′ × 8′ spacing. Closer spacing can seldom be justified to reduce loss of either wood quality or volume. Planting of 600 to 1000 or more trees per acre usually provides additional trees to die from crowding and more volume to be removed in costly precommercial thinnings. On the other hand, planting less than 300 trees per acre risks loss of quality and, in the case of pole production, volume. At extremely wide spacings, crop trees may be poorly distributed, with possible growth loss as a consequence.

In addition to financial considerations, an initial stocking of 400 trees per acre has other temporary advantages over denser stands. The recreation potential is improved because open plantings are more easily penetrated, thus making hunting, picnicking, hiking, and other similar activities possible; they also offer the increased aesthetic value of larger trees. Other advantages are that a more diverse ground cover attracts wildlife and that loss of soil moisture from transpiration is reduced for a few years. Moreover, in some localities, the added windfirmness of widely spaced trees may be of more than temporary importance.

Too often in the past, relatively close initial spacing has been used as a presumed cure for such planting ills as poor planting stock, poor planting techniques that result in low survival, off-site planting, and planting sites with excessive weed competition. These ills guarantee at least partial failure and are to be avoided. Moreover, planting too many trees per acre may have the effect of simply causing a more costly failure. However, at least one ill can be partially alleviated by initial spacing — the inclination of many to plant, but fail to tend, their trees. Where this neglect is highly probable, it may be appropriate to recommend planting as few as 200 trees per acre.

Summary

European larch can be planted at relatively wide spacings to obtain financial and other benefits. Effects of initial spacing on growth are largely transient, especially for this intolerant species. Therefore, planting at wide spacing is no substitute for timely thinnings. Nor is close spacing a suitable substitute for poor planting stock, shoddy techniques, inappropriate sites, or inadequate site preparation.

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