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Biomass Production of 4- to 9-Year-Old Intensively Cultured Larix Eurolepis Growth

in "Scotch Plaid" Plots in Wisconsin

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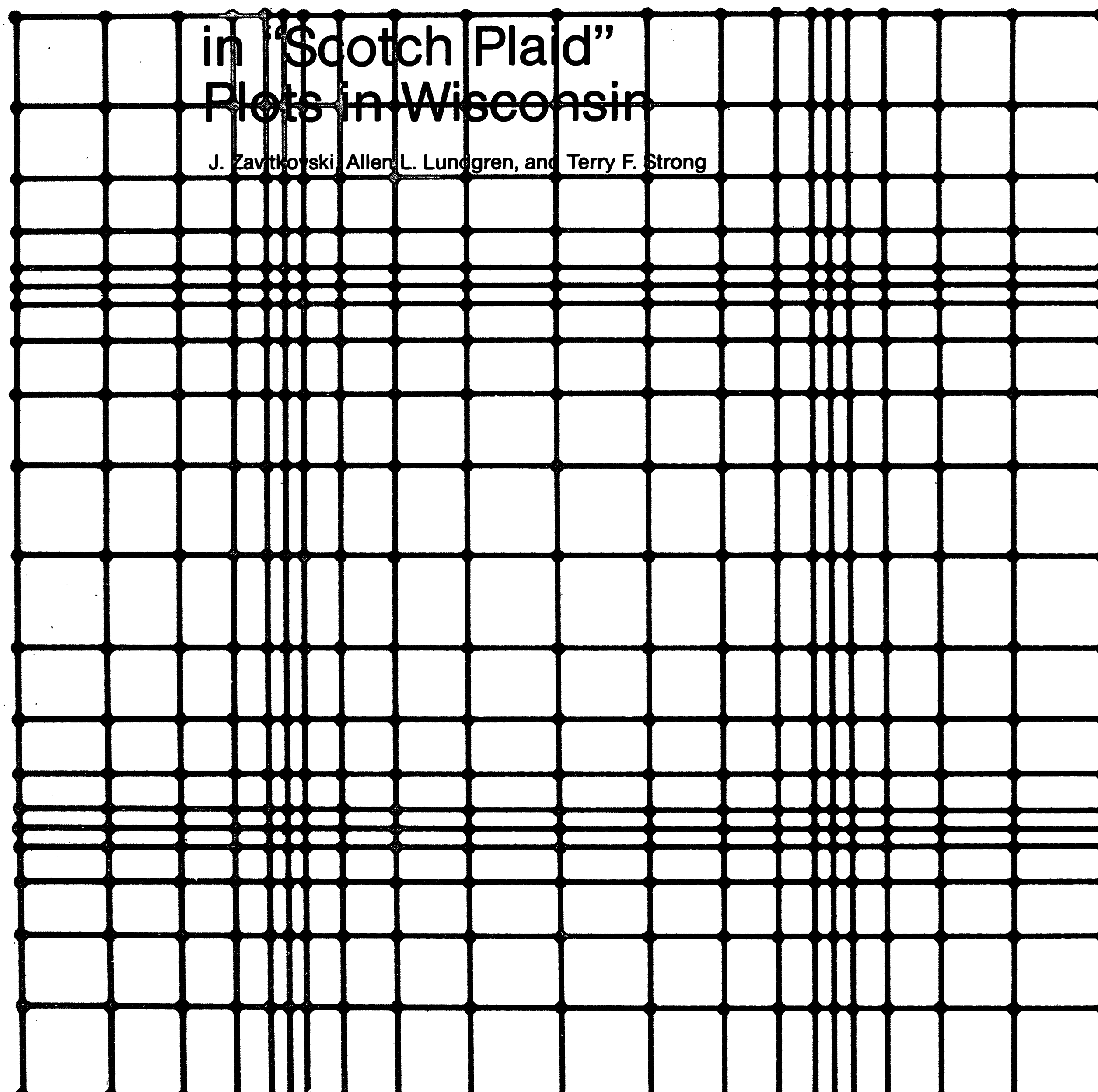

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Intensively cultured *Larix eurolepis* at age 9 averaged 7.6 m in height and, depending on the spacing, 2.3 to 6.4 cm in d.b.h. The total stem-branch biomass for all spacings tested (0.1 to 1.5 m^2) averaged 67 mt/ha and the mean annual biomass increment 7.4 mt/ha. The "Scotch Plaid" design appears suitable for comparative studies dealing with spacing and rotation.

KEY WORDS: Irrigation, fertilization, growth, allometry, fiber production, multispaced plots, growth equations, biomass distribution.

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BIOMASS PRODUCTION OF 4- TO 9-YEAR-OLD INTENSIVELY CULTURED LARIX EUROLEPIS GROWN IN "SCOTCH PLAID" PLOTS IN WISCONSIN

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The objective of this study was to evaluate production potential of *Larix eurolepis,* a hybrid of the European *L. decidua* and the Japanese *L. leptolepis,* under intensive culture and to identify combinations of spacing and rotation that maximize biomass production. Previous studies with *Populus* (Dawson *et al.* 1976, Ek and Dawson 1976, Zavitkovski *et al.* 1976), jack pine (Zavitkovski and Dawson 1978b), and tamarack (Zavitkovski and Dawson 1978a) have indicated that biomass production in stands under intensive culture is significantly higher than under traditional management practices. The studies suggest that wide application of the intensive culture system would help satisfy the increasing demand for fiber in the United States and could provide an alternate energy source or raw materials for synthesis of chemicals that have been traditionally derived from crude oil (Zavitkovski 1979).

The selection of *L. eurolepis* for this study was not accidental. The hybrid has an excellent reputation as a high-volume producer and appears to be well-adapted to a variety of climates in Europe (Ovington 1956, Keiding 1962, 1980). Recently, its suitability for kraft pulping of whole-tree chips has been reported by Isebrands *et al.* (1982).

Because only a limited quantity of the hybrid seed was available for this study, establishment of sizeable, uniformly spaced plantings was not possible. Multiple-spaced plots, such as introduced by Nelder (1962), or "Scotch Plaid" plots proposed by Lundgren (unpublished) were the logical designs for our study. "Scotch Plaid" design was used primarily because of its regular—i.e., square and rectangular—plots. Evaluation of the design and its suitability for forestry research were equally important objectives for our study.

METHODS AND MATERIALS

The plantations were established in July 1972 in the Forestry Sciences Laboratory nursery at Rhinelander, Wisconsin. The seedlings were grown for 8 weeks in a greenhouse in Jiffy 7 containers from seed of *Larix eurolepis* provided by Dr. Helmuth Barner from the Danish State Forestry Tree Improvement Station.

The plantings used a replicated square plot design containing systematic variation in tree spacing developed by Lundgren in 1965 (unpublished) as an alternative to the circular-plot systematic design suggested by Nelder (1962). Lundgren's "Scotch Plaid" design calls for establishing individual plots consisting of rows of trees planted at ever-increasing spacing on both the X and Y axes from a common point of origin (fig. 1a). This provides for testing, using relatively few trees, a wide range of spacing distances and growing-space areas with square to rectangular configurations. The spacing distances are determined by the conditions and objectives of the experiment. The idea behind this design is not only to provide the entire range of spacings within one plot, but also to serve as a living "production surface" for use in field demonstrations.

Multiple replications of plots provide the numbers of trees at each spacing necessary for analysis. The basic replication is a cluster of four adjoining plots with identical spacings, but with different orientations of the expanding rows (fig. 1b). Multiple replication clusters, shown schematically by lines representing rows of trees, give rise to the Scotch Plaid pattern (fig. 1c).

Each plot can be established with single rows for each spacing distance, double rows at each spacing, or other multiple row designs. The multiple row designs provide square spacing for one or more trees at each spacing distance.

For this study, individual plots were established with double rows for each of four spacings at 1-, 2-, 3-, and 4-ft (about 0.3-, 0.6-, 0.9-, and 1.2-m) intervals (fig. 1d). Four replications of the planting were made, consisting of two pairs of individual plots (fig. 1e). In this design, each tree in a plot occupies a unique spacing distance and configuration, but these spacing differences vary systematically and spatially (fig. 1f). This type of plot offers a wide range of square-to-rectangular spacings to test the effect on growth not only of the total growing space available to each tree, but also of the varying spacings between and within rows of trees for a given size of growing space area. The double plots were surrounded by an unplanted area about 3 m (10 ft) wide, which was kept weed-free and was irrigated with the rest of the area.

A high level of soil nutrients was maintained by annual fertilization with N, P, and K at rates of 150, 40, and 40 kg/ha (130, 35, and 35 lbs/acre), respectively. Soil moisture was kept near field capacity by irrigation as required. Weeds were controlled mechanically the first 2 years. In the droughty 1976 summer, irrigation had to be terminated by mid-July and in 1977, by oversight, no fertilizer was applied.

Height of all trees was measured annually from ages 1 to 5, and again at age 9. At ages 4, 5, and 9, diameter at breast height (d.b.h.) was measured. Biomass at ages 4, 5, and 9 was obtained by regression technique (Zavitkovski *et al.* 1974). Briefly, d.b.h. of all trees at age 9 was measured and trees were divided into four d.b.h. classes. Eight trees, two from each d.b.h. class, were harvested from an adjacent planting established for that purpose at a uniform 0.6 x 0.6 m (2 x 2 ft) spacing. Each sample tree was cut at the ground, and its d.b.h. and height were measured to the nearest millimeter and decimeter, respectively.

Branches were removed and, from each 1-m section, one branch, living or dead, was selected for dry-weight determination. Fresh weights of all branches, live and dead, as well as those of the subsample branches were obtained in the field. Stems were cut into 1-m segments and from each segment a 10-cm long disk was cut to determine dry weight. Fresh weights of the whole stem and sample disks were obtained in the field. In the laboratory, bark was removed from each disk and bark and wood were dried at 70°C to equilibrium. Sample branches were dried in the same way. Dry weights were determined to the nearest 0.1 percent of the weight. Dry weights of whole stems and branches were obtained by simple expansion.

Allometric models ($\ln Y = a + b \ln X$) were fitted separately to stem, branch, and whole-tree (above-ground) biomass data. In the equation, $\ln Y$ is the natural logarithm of component dry weight, $\ln X$ is the natural logarithm of d.b.h., and a and b are regression coefficients. Component biomass per hectare was estimated by totaling the dry weights of trees having the same growing space available in all four plots (see next paragraph) and converting the total to a hectare basis.

Each plot was subdivided by drawing imaginary lines midway between each row in each direction (fig. 1f). In this way a growing space was delineated for each tree. The outside border of trees was not used in analyzing the results. Trees falling along the diagonal running from the most dense to the most open spacing occupied square growing spaces, ranging from 1 to 4 ft (0.3 to 1.2 m) on a side, with growing spaces from 1 to 16 ft^2 (about 0.1 to 1.5 m^2). Trees on either side of this diagonal occupied rectangular plots, with mirror-image pairs of identical plots (except for directional orientation) on either side. Trees lying close to the diagonal occupied growing spaces that were only slightly rectangular in shape. Trees farthest from the diagonal had the most extreme rectangular spacing (the most extreme was 1 x 4 feet).

Each plot consisted of 49 subplots (fig. 1f) with 7 square plots and 21 different-paired rectangular plots. This wide variation in dimensions provided 25 different-sized growing space areas within one of these Scotch Plaid plots. Some growing-space areas were represented by only one tree in each replication; for example, only one tree with the 3 x 3 ft spacing occupied a 9.0 ft^2 growing space. Some growing-space areas, such as the 6.0 ft^2 size, were represented by several trees in a replication (two trees at 2 x 3 ft spacing and two at 1½- x 4 ft spacing for the 6.0 ft^2 growing space).

The number of available subplots was reduced because of the absence of a buffer zone around the basic

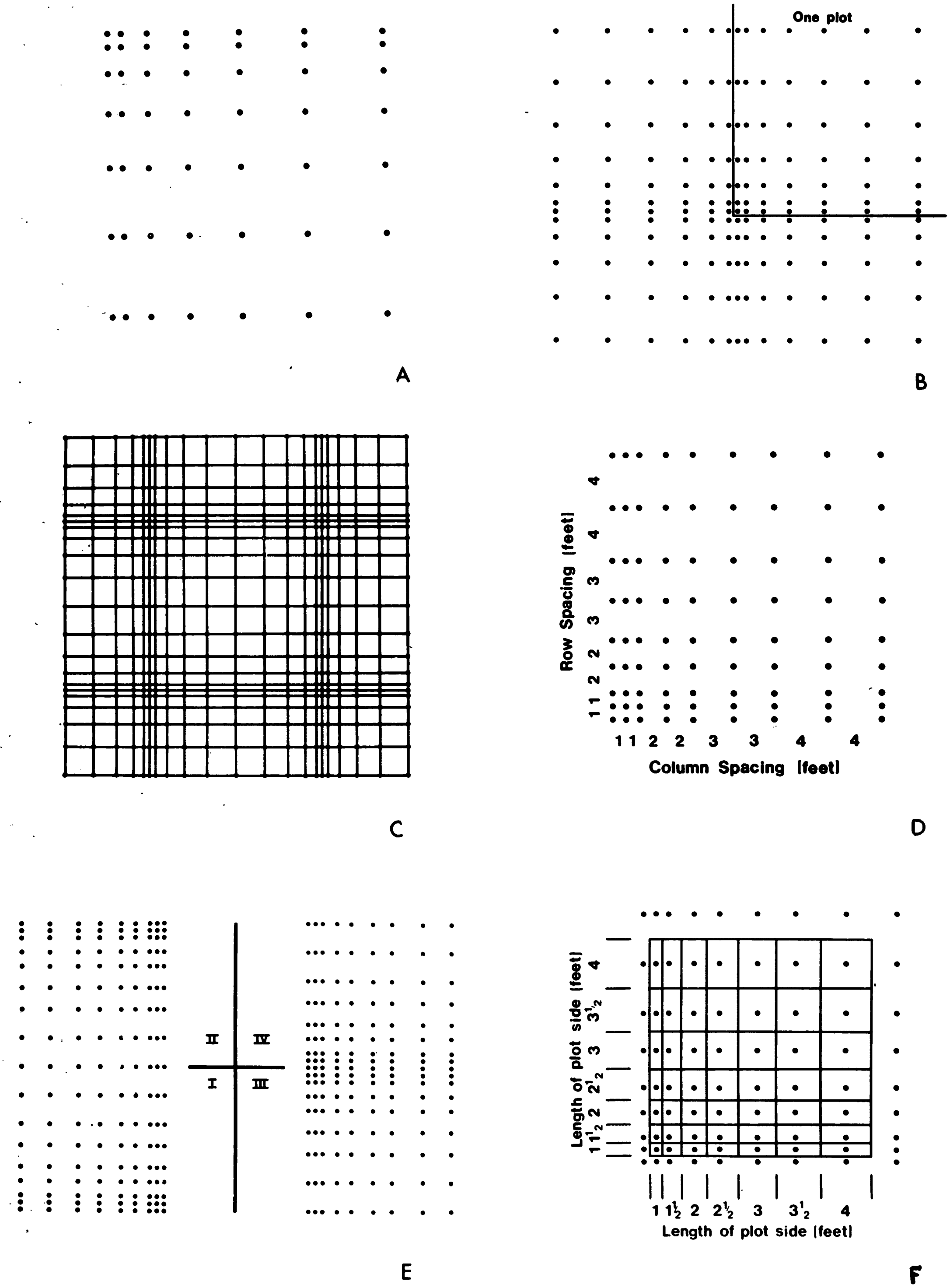

Figure 1.—(A) *A single plot of the Scotch Plaid design, with single rows of systematically increasing spacing. (B) A fully-replicated Scotch Plaid plot design, with 4 adjoining single plots. (C) A schematic diagram, with lines indicating rows of trees, of a solid block of 16 replicated plots forming a Scotch Plaid experimental plot design. (D) A single Scotch Plaid plot used in studying* Larix eurolepis, *with two rows at each spacing from 1 to 4 feet. (E) Four replications of the double-row Scotch Plaid plot design used in studying* Larix eurolepis. *(F) Sub-plot dimensions in feet for those trees used in analyzing* Larix eurolepis *yields, for a single Scotch Plaid plot.*

plots. We decided to avoid the outer row if its d.b.h. was significantly greater than the d.b.h. of the second row, and to avoid the second row if its d.b.h. was greater than that of the third row. Only one row along the 4-ft-wide border had to be avoided, but two rows along the S-N 1-ft-wide border and one along the E-W 1-ft-wide border were avoided. By joining two basic plots side-by-side, a few subplots were gained in both double-plot blocks. Finally, 182 subplots, unequally divided among the 25 different growing spaces, were used in calculating component biomasses. To reduce the variability inherent in estimating component biomasses from a few trees, these 25 different spaces were consolidated into five growing space classes, and biomasses were averaged for each class.

RESULTS AND DISCUSSION

Growing Space and Height and D.b.h. Growth

Height growth during the first 2 years was slow, but thereafter to age 9 heights increased by about 1 m (3.3 ft) per year and averaged 7.5 m (25 ft) at age 9 (fig. 2). The initial effect of the available growing space on height growth was small, and has increased only moderately with time. During the first 5 years, only heights of trees in the dense plot parts were significantly smaller than heights in the rest of the plot. At age 5, the difference between the extremes was about 0.8 m (2.7 ft), only about 25 percent of the average height.

Diameter-growth, however, was strongly affected by growing space (fig. 3, table 1), with average d.b.h. increasing with the available growing space. For example, at age 4 the extreme values were 0.76 and 1.8 cm (a difference of 135 percent) in the 1-2½ and 7½-10 ft² classes, respectively. This relation remained about the same at ages 5 and 9.

Height growth of our intensively cultured *L. eurolepis* was substantially more rapid than that reported in the literature for the same hybrid or other pure *Larix* species grown under traditional silvicultural systems. In Poland (Chodzicki 1967), height of 13-year-old trees of L. *decidua*, *L. leptolepis*, and *L. eurolepis* averaged 6.8, 6.1, and 7.0 m, respectively. Our trees averaged 7.5 m at age 9. In Czechoslovakia (Machanicek and Prudic 1978), heights of 9-year-old *L. decidua* and *L. eurolepis* averaged 3.8 and 5.2 m, respectively. Although the hybrid grew better than the local source, its height lagged several years behind the intensively cultured hybrid in our

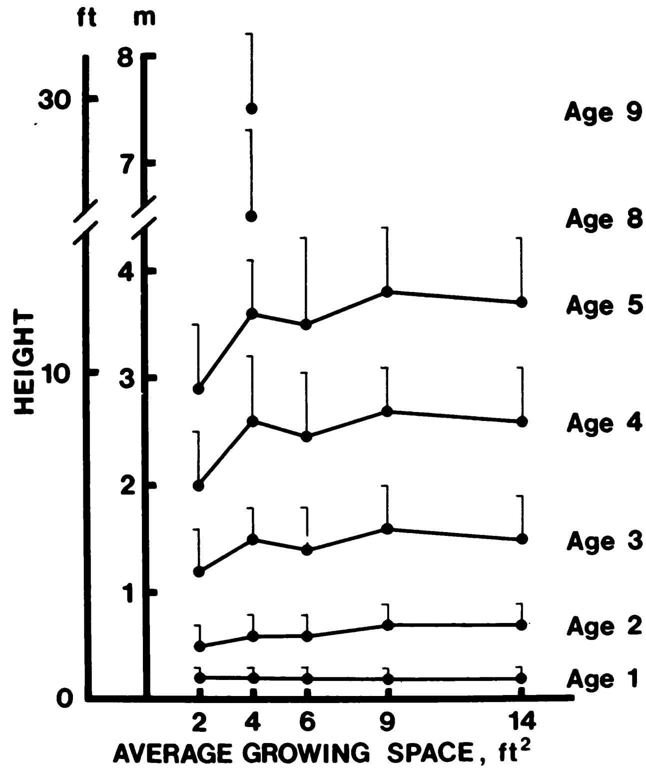

Figure 2.—*Height of 1- to 9-year-old* Larix eurolepis *trees in plots of increasing growing space. Site index of 35 m was calculated according to Laidly (1979) using regression coefficients for tamarack. The height at 8 years is from Isebrands* et al. *(1982). Bars represent one standard deviation.*

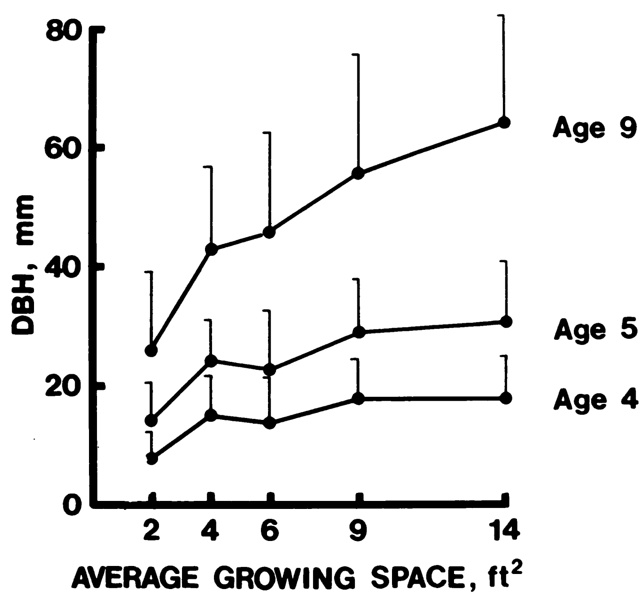

Figure 3.—*Diameter breast height (d.b.h.) of 4-, 5-, and 9-year-old* Larix eurolepis *in plots of increasing growing space. Bars represent one standard deviation.*

Table 1.—*Survival and d.b.h. distribution of* Larix eurolepis *trees*

Growing space (ft²)	Trees planted	Age 4 Survival	Age 4 Mean[1]	Age 4 SD	Age 5 Survival	Age 5 Mean[1]	Age 5 SD	Age 9 Survival	Age 9 Mean[1]	Age 9 SD
	Number	*Percent*	*mm*		*Percent*	*mm*		*Percent*	*mm*	
1-2½	21	81	7.6[a]	4.6	76	14.1[a]	6.1	33	25.9[a]	13.1
3-4½	43	98	15.0[bc]	6.2	95	24.3[b]	6.7	79	43.0[b]	13.4
5-7	45	98	14.0[b]	7.4	96	22.9[b]	9.7	73	45.7[bc]	16.8
7½-10	38	97	17.6[c]	6.3	97	29.0[c]	8.7	92	55.8[cd]	19.9
10½-16	35	100	17.4[c]	7.3	100	31.0[c]	10.0	91	64.5[d]	18.5
All	182	96	15.3	6.6	94	25.4	9.1	77	50.8	17.9

[1]Values with the same letter in each column are not significantly different ($p = 0.05$).

study. Also in several areas in Denmark (Keiding 1980) the height of *L. eurolepis,* although better than heights of *L. decidua* and *L. leptolepis,* was one to several years behind the average height of our trees. Average heights of traditionally cultured hybrid larch in research plots at Rhinelander ranged from 1.3 to 2.3 m at age 5 and from 3.2 to 5.0 m at age 8 (personal communication from Dr. H. Nienstaedt). The intensively cultured hybrid larch averaged 6.5 m (±0.8 m) at age 8 (Isebrands *et al.* 1982).

Whereas heights of our intensively cultured hybrid were consistently better than heights of *Larix* at other locations, the d.b.h. comparisons were more complex, partly because of the strong effect of spacing on d.b.h. growth. In Czechoslovakia (Machanicek and Prudic 1978), the average d.b.h. of 9-year-old *L. eurolepis* in 1 x 1 m plantations was 5.5 cm; our similarly spaced trees (0.9 x 0.9 m or 3 x 3 ft) averaged 5.6 cm. In Denmark (Keiding 1980), 8-year-old plantings spaced 2 x 2 m averaged 6.9 cm at Ulvedal and 8.7 cm at Gurre Vang. Our 9-year-old trees averaged 6.4 cm at the 1.2 x 1.2 m (4 x 4 ft) spacing. A comparison of these data clearly indicates that trees grown under intensive culture are more slender than trees in the traditional silvicultural system. A slenderness index, height in m divided by d.b.h. in cm, can be used to compare the form of forest trees (Rudolf 1951). The index was 0.95 for the hybrid in Cezchoslovakia, about 0.8 for the hybrid in Denmark, and 1.19 for our trees at 1.2 x 1.2 m spacing.

Compared with a traditionally grown tamarack, *L. laricina,* the intensively cultured hybrid was superior in both height and d.b.h. growth. Heights of trees from various tamarack provenances ranged from 2.1 to 3.2 m at age 9 (Jeffers 1975) and from 4.4 to 6.4 m at age 14 (Riemenschneider and Jeffers 1980). The d.b.h. of 14-year-old tamarack ranged from 5.3 to 8.3 cm, and the slenderness index was about 0.8. Seven-year-old, intensively cultured tamarack (Zavitkovski and Dawson 1978a) in 0.6 x 0.6 m (2 x 2 ft) plantings averaged 4.0 m in height and 2.8 cm in d.b.h. Their slenderness index was 1.60, suggesting again that trees under intensive culture are more slender than trees grown under traditional silvicultural systems.

Growing Space and Survival

Survival was positively related to available growing space and negatively to age (table 1). At age 4, for all spacings, survival averaged 96 percent, but was only 81 percent in the densest plot part. By age 9, only 33 percent of the trees in the densest plot parts were still alive. In plots with more growing space, survival exceeded 90 percent. A positive relation between survival and growing space in intensively cultured tamarack was also reported by Zavitkovski and Dawson (1978a). At age 7, in plantings with square spacings of 0.23, 0.30, and 0.61 m, the survival was 48, 64, and 64 percent, respectively.

Destructively Sampled Trees

Biomass distribution among tree components and dry weight as percent of fresh weight were determined for the eight destructively sampled trees harvested in mid-February 1981.

Biomass distribution

On the average, stems accounted for 71 percent and branches for 29 percent of the whole tree (aboveground) dry weight (table 2). There was no evident relation between tree size and biomass distribution. Stem wood accounted for 81 percent and stem bark for 19 percent of the total stem. These percentages varied little over the d.b.h. range of sampled trees (26 to 64 mm). Biomass distribution between stems

Table 2.—*Biomass distribution among tree components in 9-year-old destructively sampled* Larix eurolepis

(In percent)

D.b.h. range (mm)	Trees	Whole tree[1]		Stem	
		Stem	Branches[2]	Wood	Bark
	Number				
26–32	2	65–73	27–35	75–81	19–25
38–45	2	61–77	23–39	79–81	19–21
46–60	2	78–79	21–22	82–83	17–18
62–64	2	63–72	28–37	81–83	17–19
Mean		71	29	81	19

[1]Above ground.
[2]Live and dead without needles.

and branches was similar to that for 7-year-old intensively cultured tamarack (Zavitkovski and Dawson 1978a) spaced at 0.3 x 0.3 m (1 x 1 ft): 70 and 30 percent, respectively. However, in tamarack spaced at 0.6 x 0.6 m (2 x 2 ft), stems made up only 56 percent of whole tree dry weight—considerably less than for the hybrid at this spacing. The percentage of stem wood in the hybrid (81 percent) was moderately higher than that of stem wood in the 7-year-old tamarack, which averaged 76 percent in all three spacings. Ten-year-old *L. eurolepis* in Cezchoslovakia had 62 and 38 percent of the total biomass in stems and branches, respectively.

Dry weight/fresh weight relation

More than one-half of the stem fresh weight was water, with slighly more water in stem bark (59 percent) than in stem wood (56 percent) (table 3). Only 40 percent of the branch weight was water, most likely because both live and dead branches were pooled into one branch component. Branch water content appeared to be positively related with tree size, suggesting that the percentage of live branches on large trees was higher than on small trees. In Great Britain, stems and branches of 23-year-old *L. eurolepis* had 61 percent and 55 percent water, respectively (Ovington 1956).

Growing Space and Biomass Production

Biomass growth model

An allometric (double logarithmic) model based on d.b.h. was fitted to component dry weights of the 9-year-old destructively sampled trees (table 4). Separate equations were calculated for stem wood, stem

Table 3.—*Dry weight (as percent of fresh weight) of tree components of 9-year-old destructively samples* Larix eurolepis

D.b.h. range (mm)	Trees	Stem wood	Stem bark	Branches[1]
	Number			
26–32	2	47–50	38–40	62–73
38–45	2	41–45	37–42	59–62
46–60	2	43–44	41–42	52–60
62–64	2	41–42	42–43	50–61
Mean		44	41	60
SD	—	3	2	7

[1]Live and dead without needles.

bark, total stem, live and dead branches, and whole tree (aboveground). The trees were harvested in an area specifically established for that purpose at a uniform 0.6 x 0.6 m (2 x 2 ft) spacing. It is likely that these equations would best fit trees growing under similar spacings and may be less accurate for trees growing in the denser and more open parts of the plantings. In previous studies with tamarack and jack pine (Zavitkovski and Dawson 1978a, 1978b), different allometric equations were prepared for stands spaced 0.3 x 0.3 and 0.6 x 0.6 m (1 x 1 and 2 x 2 ft).

No trees were harvested at ages 4 and 5, thus no specific biomass equations are available for those ages. Instead, biomass equations for the 9-year-old trees were used for the younger stands. We don't know what error this may have introduced, but we believe it to be small. In the previously cited biomass studies on tamarack and jack pine, no significant differences were found between regression coefficients for 6- and 7-year-old trees. In other studies, one set of regressions has been used to estimate biomass of tree components in stands featuring a wide range of ages (Zavitkovski 1971, Hegyi 1972, Zavitkovski and Stevens 1972, MacLean and Wein 1976, Green and Grigal 1978).

Whole tree biomass and mean annual biomass increment (m.a.b.i.)

Whole-tree biomass was most likely highest at the 1-2½ ft^2 spacing for the first 2 or 3 years, but at age 4 the 3-4½ ft^2 spacing became the most productive and remained the most productive through age 9 (table 5). At the same time, the whole-tree biomass of the three upper classes was increasing rapidly. At age 9, all four upper classes had biomasses significantly higher than the first class, which passed its

Table 4.—*Coefficients of allometric regression equations for dry weights of 9-year-old trees of* Larix eurolepis

Tree component	Trees	Regression coefficients[1]				Correction factor[2]
		a	b	R^2	$S_{y \cdot x}$	
	Number					
Whole tree[3]	8	-2.0108	2.1517	0.9707	0.1326	1.0088
Stem wood	8	-2.7292	2.2572	.9745	.1296	1.0084
Stem bark	8	-3.6793	1.9289	.9832	.0895	1.0040
Total stem	8	-2.4152	2.1903	.9787	.1146	1.0066
Live and dead branches	8	-3.1097	2.0409	.8077	.3532	1.0644

[1]For model $Y = a + bX$ where Y is *ln* (dry weight) and X is *ln* (d.b.h.). Dry weights are in kg and d.b.h. in cm.
[2]According to Baskerville (1972).
[3]Above ground without needles.

Table 5.—*Total biomass distribution in relation to growing space of 4- to 9-year-old* Larix eurolepis *stands*
(In metric tonnes/ha dry weight)

Growing space class (ft²)	Age 4			Age 5			Age 9		
	Stem	Branch	Whole	Stem	Branch	Whole	Stem	Branch	Whole
	Mean (SD)								
1-2½	4.3	2.3	6.6	11.2	5.5	16.7	19.6	8.7	28.3
	(2.3)	(1.2)	(3.5)	(5.5)	(2.5)	(8.0)	(13.6)	(6.0)	(19.6)
3-4½	8.1	3.9	12.0	19.6	8.8	28.4	57.9	25.7	83.6
	(2.7)	(1.3)	(4.0)	(3.6)	(1.6)	(5.2)	(8.8)	(5.4)	(14.2)
5-7	4.6	2.2	6.8	12.1	5.5	17.6	40.4	16.5	56.9
	(0.7)	(0.3)	(1.0)	(1.5)	(0.6)	(2.1)	(8.0)	(2.9)	(10.9)
7½-10	4.4	2.1	6.5	12.6	5.6	18.2	52.6	20.9	73.5
	(0.9)	(0.4)	(1.3)	(2.9)	(1.3)	(4.2)	(19.7)	(7.5)	(27.2)
10½-16	3.1	1.4	4.5	10.0	4.4	14.4	43.9	17.2	61.1
	(0.8)	(0.4)	(1.2)	(2.6)	(1.1)	(3.7)	(10.5)	(3.9)	(14.4)
Mean, all	5.1	2.4	7.5	13.5	6.1	19.6	46.7	19.6	67.3
SD	(1.6)	(0.8)	(2.4)	(3.1)	(1.4)	(4.5)	(12.8)	(5.3)	(18.1)

most productive years before age 5. For the four upper classes at age 9, the whole-tree biomass averaged almost 69mt/ha (31 tons/acre) and the mean annual biomass increment about 7.7 mt/ha (3.4 tons/acre) (table 5, fig. 4).

Figure 4 shows the relation between the m.a.b.i. and the available growing space. Linear regressions fitted to the 4- and 5-year-old production data had a negative slope, indicating that the densest spacings produced more biomass than the more open spacings. At age 9, the slope of the regression changed to positive, suggesting that the highest productivity shifted to the wider spacings. This change resulted primarily from two factors: a high mortality in the denser plots (table 1) and an increased biomass growth in the widely spaced parts of the plantings (table 5). It is almost certain that in future years the positive slope of the regression line will become steeper and the highest m.a.b.i. will shift to the more open parts of the plantings. A similar shift in m.a.b.i. with time from dense to more open spacings was also observed in the previously discussed studies on tamarack and jack pine (Zavitkovski and Dawson 1978a, 1978b) and has been seen broadly in other studies dealing with spacing and production (Harms and Langdon 1976, Steinbeck and Brown 1980, Heilman and Peabody 1981).

The whole-tree biomass production of intensively cultured *L. eurolepis* was about 50 percent higher than the best attained in intensively cultured tamarack (Zavitkovski and Dawson 1978a). The highest m.a.b.i. of the 7-year-old tamarack was 5.2 mt/ha, of which 4.0 mt/ha was accounted for by stems. The 9-year-old *L. eurolepis* averaged 7.5 mt/ha (stems 5.2 mt/ha) and the m.a.b.i. is still increasing. Traditionally cultured *L. eurolepis* in Great Britain (Ovington 1956) had a m.a.b.i. of 6.4 mt/ha at age 23, of which stems accounted for 3.3 and branches with needles for 3.1 mt/ha.

Comparison of biomass production in square and rectangular plots

Only 9 out of 81 plots per replication were squares; the remaining 72 plots were rectangles of various shapes (fig. 1f). The question inevitably arises as to which shape provides a better environment for tree

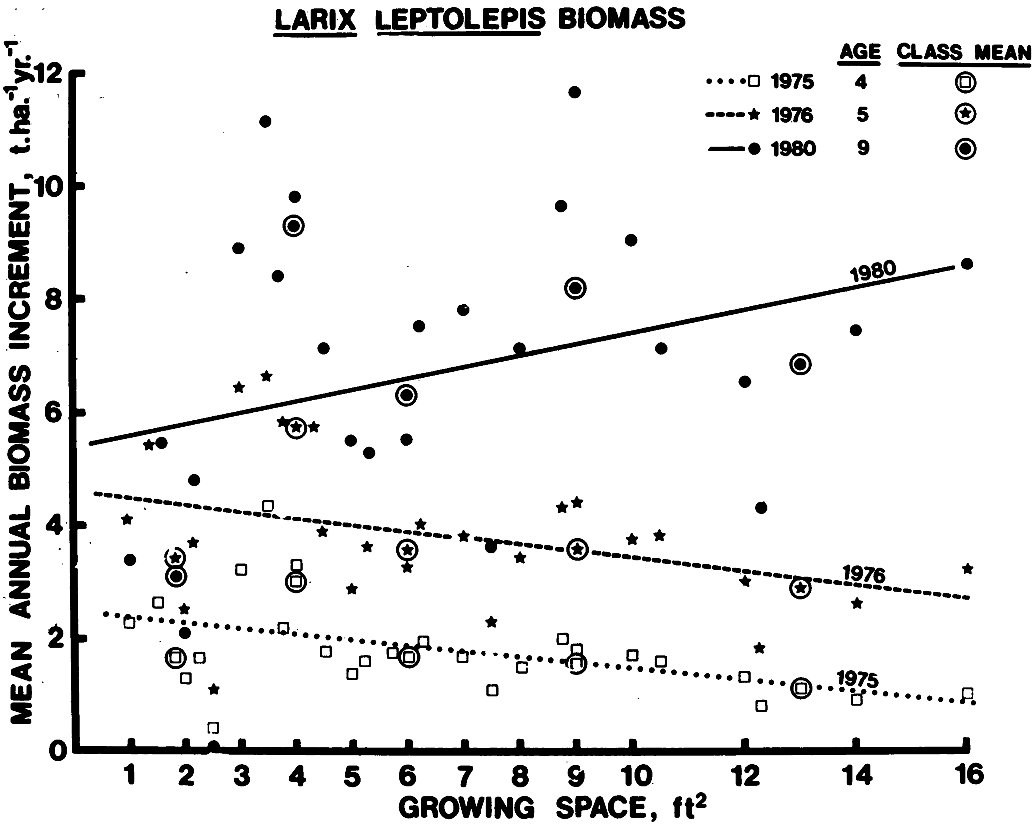

Figure 4.—*Trends of mean annual biomass increment of* Larix eurolepis *as affected by the available growing space at ages 4, 5, and 9 years.*

growth. Our comparison indicated that, on the average, the biomass was about the same in both square and rectangular plots of the same or similar growing space (t = 0.45) (table 6). The nonsignificant difference between shapes may have resulted in part from a rather high variability of the data, but it should be noted that the variability of both data sets was almost the same. Some of the very high values—e.g., equivalent of 110 mt/ha in the 1 x 4 ft plots—may be explained by the proximity of these plots to the planting border. At age 9, disregarding the shape of the plot, the total biomass in plots having growing spaces of 8¾ ft² or greater averaged about 30 percent higher than the biomass in plots with smaller growing spaces. The differences, although nonsignificant, are also indicative of the steadily increasing productivity in larger plots as suggested in figure 4.

The Application of the "Scotch Plaid" Design

The first attempt to incorporate various spacings into a single plot was made by Nelder (1962), who also provided the rationale for its use. The original Nelder plots were circular-spoke designs in which tree spacing was controlled by the number of spokes and distance between adjacent arcs. This design, which has been successfully used in many studies, compares favorably with traditional designs (Smith 1978, Lemoine 1980).

Table 6.—*Comparison of total biomass at age 9 in square and rectangular plots of identical or similar area*

Square plots			Rectangular plots		
ft/s2	Size, ft	Biomass, t/ha	ft/s2	Size, ft	Biomass, t/ha
1	1x1	30.4	1½	1x1½	48.8
2¼	1½x1½	43.2	2	1x2	19.1
4	2x2	51.9	4	1x4	110.0
			3¾	1½x2½	75.8
			4½	1½x3	63.9
6¼	2½x2½	67.6	6	2x3	68.5
			6	1½x4	33.6
9	3x3	104.4	8¾	2½x3½	86.1
			10	2½x4	81.0
12¼	3½x3½	38.6	12	3x4	58.5
16	4x4	77.8	14	3½x4	66.4
Mean		59.1			64.7
SD		25.9			25.0
CV%		44			39

Lundgren (unpublished) modified the irregular arc-spoke design of the Nelder plots by incorporating squares and rectangles of increasing size into a basic square-plot design (fig. 1b). By joining four of these basic plots, a complete "Scotch Plaid" design is achieved which, except for its shape, is equivalent to the complete Nelder design. The densest spacings should be located in the center of the "Scotch Plaid" design. Having the more open spacings on the outside will reduce the number of rows needed for the buffer zone, which should be about 1.5 to 1.6 m wide for hybrid poplars (Bowersox and Ward 1976, Zavitkovski 1981) and at least 1 m wide or one row for wider spacings in conifers with a strongly expressed geotropism, such as pines (Sijde 1975, Zavitkovski and Dawson 1978b) and larches (Zavitkovski and Dawson 1978a, this study).

The main advantage of the "Scotch Plaid" design, in comparison to the original Nelder plots, is the regularity of individual subplots and their arrangement in rows. They resemble the traditional plantation designs.

CONCLUSIONS

1. *Larix eurolepis,* a hybrid between *L. decidua* and *L. leptolepis,* proved to be a promising hybrid for production of great quantities of fiber or energy material under short-rotation intensive culture.
2. During the first 9 years, trees grew at an average annual rate of about 0.9 m (3 ft) in height and, except for the densest spacings, showed little variability in height growth in relation to the available growing space. Diameter growth, however, was strongly affected by density. At age 9, the average d.b.h. ranged from 2.3 to 6.4 cm (0.9 to 2.5 in.) in the dense and open plot parts, respectively.
3. At age 9, the total stem-branch biomass in plots with a growing space of 0.3 m^2 (3 ft^2) and greater averaged about 69 mt/ha (31 tons/acre) and the m.a.b.i. was 7.6 mt/ha (3.4 tons/acre). The data indicated that higher biomass yields will be reached at spacings of 1 to 1½ m^2, (i.e., about 9 to 16 ft^2) in the next 5 to 10 years.
4. A shift in biomass production in response to the available growing space occurred between ages 5 and 9. At age 5, the densest plot parts were the most productive but the trend was reversed to more open plots at age 9.
5. The "Scotch Plaid" design appears suitable for this kind of comparative study for which only a limited quantity of genetically improved seed is available.
6. The "Scotch Plaid" design incorporates square and rectangular plots of various sizes. At age 9, no significant difference was found in total biomass between the square and rectangular plots of similar sizes. This suggests that both square and rectangular plots can be used operationally with the same result.

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