beschrieben. — Als Hauptergebnis wird herausgestellt, daß die einzelnen Herkünfte selbst schon sehr variable Populationen darstellen, daß aber diese Variabilität die Herkünfte nicht unterscheiden läßt. Man hält die Pinus monticola für eine hochgradig heterozygote Species, so daß man solche Untersuchungen mit viel größeren Herkunftsproben durchführen müßte, um mögliche Unterschiede feststellen zu können. Außerdem sollte die Anzucht des Untersuchungsmaterials nicht nur an einem Ort, sondern an mehreren verschiedenen Plätzen geschehen.

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Geographic Variation in Japanese Larch in North Central United States Plantations

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Japanese larch (Larix leptolepis [SIEB. and ZUCC.] GORD.) has a limited natural range in the central part of the principal Japanese island, Honshu (Figure *1*). The species grows naturally in scattered stands at elevations of 900 to 2,500 meters. All the natural stands are included in an area about 200 km square.

This larch has been planted extensively in Japan and also in Europe. It has recently attracted the attention of American foresters, particularly in New York. When planted on suitable sites it usually outgrows the commonly planted pines and spruces.

Hybrids between Japanese and European (Larix decidua MILL.) larches have been known since 1900. They grow vigorously in many parts of northern Europe and can be produced easily. In the past decade tree breeders in Hokkaido, northern Japan, have concentrated on hybrids between Japanese and Dahurian larch (L. *gmelini* [RUPR.] LITVIN.) which can be produced in large quantities and show promise for northern localities.

Data on genetic variation within Japanese larch have been scanty, based on a few unreplicated progeny tests. The present provenance study was undertaken to determine the range of genetic variability within the species, determine the nature of the variation pattern, and to provide practical

[1]) Dr. PAULEY died in 1970. He had been a member of the staff of the School of Forestry of the University of Minnesota at St. Paul since 1955. Because he was a well known scientist and because of his long interest in larch improvement, the other authors wish to dedicate this article to him.

[2]) The other authors are located as follows: FARNSWORTH — Michigan Dept. of Natural Resources, Crystal Falls; GATHERUM — Dept. of Forestry, Ohio State University, Columbus (formerly at' Iowa State University at Ames); JOKELA — Dept. of Forestry, University of Illinois, Urbana; KRIEBEL — Dept. of Forestry, Ohio Agricultural Research and Development Center, Wooster; LESTER — Dept. of Forestry, University of Wisconsin, Madison; MERRITT — Dept. of Forestry and Conservation, Purdue University, W. Lafayette, Indiana; READ — Rocky Mountain Forest and Range Experiment Station, Lincoln, Nebraska; SAJDAK — Dept. of Forestry, Michigan Technological University, Houghton; WRIGHT — Dept. of Forestry, Michigan State University, E. Lansing. The work reported here is part of the NC-51 project "Improvement of forest trees through selection and breeding", financed in part by regional research funds from the U. S. Dept. of Agriculture. Approved for publication as Journal Article No. 5372 of the Michigan Agricultural Experiment Station.

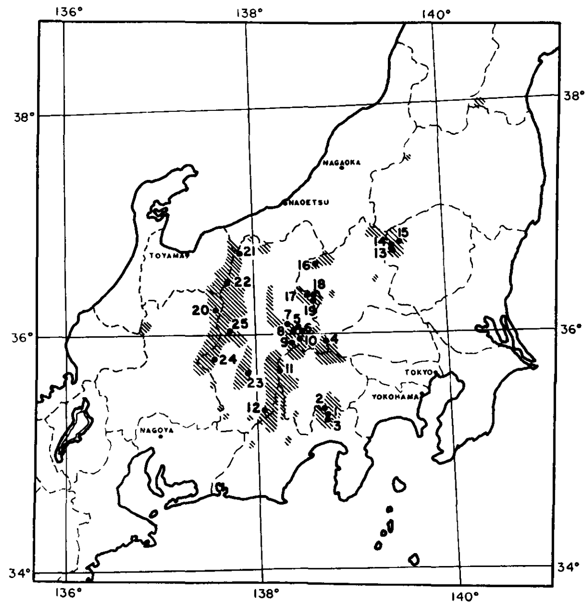

Figure 1. — Natural range (shaded) of *Larix leptolepis* in central Honshu, Japan and location (numbered dots) of stands from which seed was collected.

information for tree planters in north central United States.

The provenance experiments reported here are part of a much larger study. The same provenances were planted at 13 locations in West Germany (Langner and Stern, 1965; Hattemer, 1968, 1969; and Schönbach *et al.*, 1966); at one place in New York (Stairs, 1965); and in Japan. There have been previous reports on the NC-51 plantations in Iowa (Kepler and Gatherum, 1964); Minnesota (Pauley, Mohn and Cromell, 1965); and Nebraska (Read, 1970). Data from the papers by NC-51 members are included here.

Materials and Methods

The Government Forest Experiment Station, Meguro, Tokyo, Japan arranged for the collection of seed from 25 natural stands of Japanese larch in 1956. The collections represented all parts of the species' range (*Figure 1, Table 1*). Each seedlot contained seed from several average trees in one stand. These seed collections were shared with:

Branches of the Government Forest Experiment Station in Japan,

Institut für Forstgenetik und Forstpflanzenzüchtung, Schmalenbeck, West Germany,

College of Forestry of the State University of New York at Syracuse, and

Michigan State University.

The 7-origin experiment. — The NC-51 study consists of two separate experiments. In the first, of seven origins, seed was sown May 2, 1958 in an experimental nursery at East Lansing, Michigan. A randomized complete block design with four replications was used. Each plot consisted

Table 1. — Location, climate, and characteristics of the 22 parental stands of *Larix leptolepis*.

Schmalenbeck No. (MSFG No.)	North Lat.	East Long.	Elev.	Mean annual temp.[1])	Mean annual prec.[1])	Age	Ht.	DBH
	°	°	m	°C.	mm	yrs.	m	cm
Mt. Fuji								
1 (111)	35.4	138.7	1320	6.2	1820	75	17	39
2 (112)	35.4	138.7	1760	5.0	1760	75	19	34
Mt. Azusa								
4 (3, 114)	36.0	138.7	1500	6.5	1360	40	16	27
Yatsuga Mountains								
5 (115)	36.0	138.4	1780	6.1	1550	75	19	41
6 (116)	36.0	138.4	1750	5.4	1480	70	21	42
7 (117)	36.1	138.3	1600	5.1	1430	—	23	42
8 (118)	36.0	138.3	1700	5.4	1700	60	20	35
9 (4, 119)	35.9	138.3	1450	6.8	1560	55	20	42
10 (120)	35.9	138.3	1750	6.1	1330	55	21	36
Akaishi Mountains								
11 (121)	35.8	138.2	1500	6.5	1720	65	18	31
12 (6, 122)	35.4	138.1	2000	4.0	2840	130	20	41
Mt. Nantai								
13 (123)	36.8	139.4	1360	5.5	2250	60	20	44
14 (124)	36.8	139.4	1490	6.8	2470	60	27	57
15 (2, 125)	36.8	139.5	1700	5.3	2590	65	15	42
Mt. Shirane								
16 (1, 126)	36.6	138.5	1750	4.3	1800	70	21	46
Mt. Asama								
17 (127)	36.4	138.5	1900	3.2	1890	70	14	35
18 (128)	36.4	138.6	1420	6.2	1400	60	23	39
19 (129)	36.4	138.5	1700	4.3	1570	50	13	29
Mt. Komaga								
23 (133)	35.8	137.9	1820	3.2	2380	120	28	54
Hida Mountains								
22 (7, 132)	36.4	137.7	1380	5.6	1670	50	12	25
24 (5, 134)	35.9	137.6	1380	6.9	2130	60	27	79
25 (135)	36.1	137.7	1920	3.3	2300	120	19	50

[1]) The temperature and precipitation data were supplied by the Japanese Forest Experiment Station at the time the seeds were sent. Dr. Tak. Furukoshi, who reviewed the manuscript, wrote that the data were probably gathered from villages a few hundred meters below the actual collecting sites. They must be used with caution.

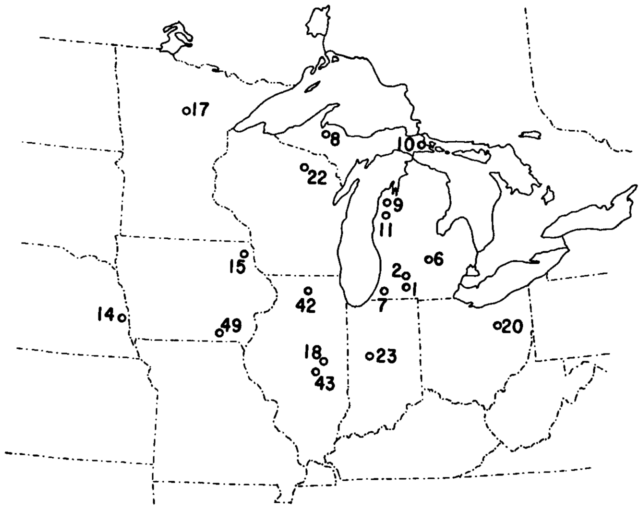

Figure 2. — Location of *Larix leptolepis* test plantations in north central United States. The 1960 plantations (with the suffix —60) include 7 origins; the 1961 plantations (with the suffix —61) include 22 origins.

of one 1.3-m row thinned to 40 seedlings; the rows were 15 cm apart. Extra seed was sown broadcast in rectangular plots thinned to a similar density. The trees were maintained weed-free and watered as needed. Germination was uniform and growth was better than obtained with other larch species in commercial nurseries.

The four replications of row-plots were maintained until age 3. In 1960, 2—0 stock was lifted from the broadcast-sown plots and used for the establishment of 17 test plantations in the north central states *(Figure 2, Table 2)*. Each plantation followed a randomized complete block design with 4-tree plots and 5 to 12 (usually 10) replications. Spacing was 2.4 × 2.4 meters. Site quality and plantation care varied within wide limits.

The 22-origin experiment. — The second experiment contained 22 origins, including the 7 in the previous experiment. The seed was sown May 14, 1959. Germination and growth were less than in the 7-origin experiment although the same experimental design and treatments were used. Nine plantations were established in 1961, using the same design described previously.

Table 2. — Location of and survival in 18 Japanese larch test plantations in north central United States. The plantations are listed in north-south order. The suffixes —60 and —61 denote respectively establishment in 1960 (7 origins) or 1961 (22 origins). Eight additional plantations in Michigan (Allegan, Cass, Crawford and Wexford Counties), Wisconsin (Oneida and Sawyer Counties) and Minnesota (Benton and Dakota Counties) were discarded because of high mortality and extremely slow growth.

Plantation number and name, name of county, name of state		Survival in 1962	Survival in 1967
		— percent —	
17—60	Gunn Park, Itasca, MINN	61	57
22—60	Starks, Oneida, WIS	83	58
8—60	Ford, Baraga, MICH	37	30
10—60	Dunbar, Chippewa, MICH	89	51
9—60	Bruning, Benzie, MICH	80	75
11—60	Manistee, Manistee, MICH	96	92
6—60	Rose Lake, Shiawassee, MICH	66	53
1—61	Kellog, Kalamazoo, MICH	88	74
2—60	Kellogg, Kalamazoo, MICH	52	38
7—61	Russ, Cass, MICH	76	60
15—60	Paint Creek, Allamakee, IOWA	92	84
42—61	Sinissippi, Ogle, ILL	80	70
49—61	Soap Creek, Davis, IOWA	70	70
23—60	Purdue, Tippecanoe, IND	82	81
20—60	Apple Creek, Wayne, OHIO	52	50
18—60	4-H Camp, Piatt, ILL	96	92
43—61	4-H Camp, Piatt, ILL	69	48
14—60	Horning Farm, Cass, NEB	62	45

Measurements. — Height, foliage color in summer and autumn, and winter injury were measured annually for 3 years in each nursery experiment. Later measurements were confined to 18 high-survival plantations and for most plantations included height, injury from growing-season frosts or winter cold, and flowering data. The frequency of such measurements varied. In a few plantations tree form, diameter, and foliage color in summer and autumn were measured.

Statistical analysis. — An analysis of variance, using plot means as items, was performed for each set of measurement data from the nursery and for a single plantation. For some traits, multi-plantation analyses of variance were performed, using origin × plantation interaction as the error term to test significance of differences among origins or among plantations. Flowering data were analyzed by Chi-square. Simple product-moment correlations were used, with origin means as items, to determine the relation between progeny performance and characteristics of the parental habitats, repeatability of the same trait in different years, similarity between plantations as regards the same trait, or relations among traits.

Results

General. — The nursery experiments were successful in showing genetic differences among origins. Height was almost twice as great at age 2 as in Hattemer's German experiment. The error variances were low, and experimental precision was equal to or superior to that found in NC-51 provenance tests with other species.

The plantations varied from almost complete failure to very successful. Initial mortality, which ranged from 4 to 86 percent, was higher than usually experienced in Japan or Europe. Four factors explain most of the initial mortality: the use of 2—0 stock rather than the 2—1 stock used in Japan, poor site quality, inadequate weed control, and planting after leafing out.

Most plantations were located on experimental forests where there was previous experience with many other tree species. On the proper soil (loam or sandy loam) the larches grew much faster than pines or spruces in the same vicinity. Only European larch grew as rapidly. Growth was very poor, however, if the Japanese larch was planted in dry sandy soils, frost pockets, or swamps.

The fastest growing plantation, in Nebraska, is illustrated in *Figure 3*. Form was good, the crowns had closed a few years after planting, and volume production was high. Rate of height growth was similar to that reported by Hattemer in Germany, but rate of diameter growth was 50% greater than in German plantations of the same age.

The general appearance of the other successful plantations was similar except that growth was somewhat less *(Table 3)*. Growth rate in the other plantations is less at age 6 than in Germany, but compares favorably with growth of planted Japanese larch in Hokkaido and on Mt. Fuji in Japan.

Mortality continued as the plantations grew older. One low-lying plantation was nearly wiped out in 1966 following a flood. Rodents took a toll in Ohio, Indiana and Illinois. There have been occasional instances of death of well-

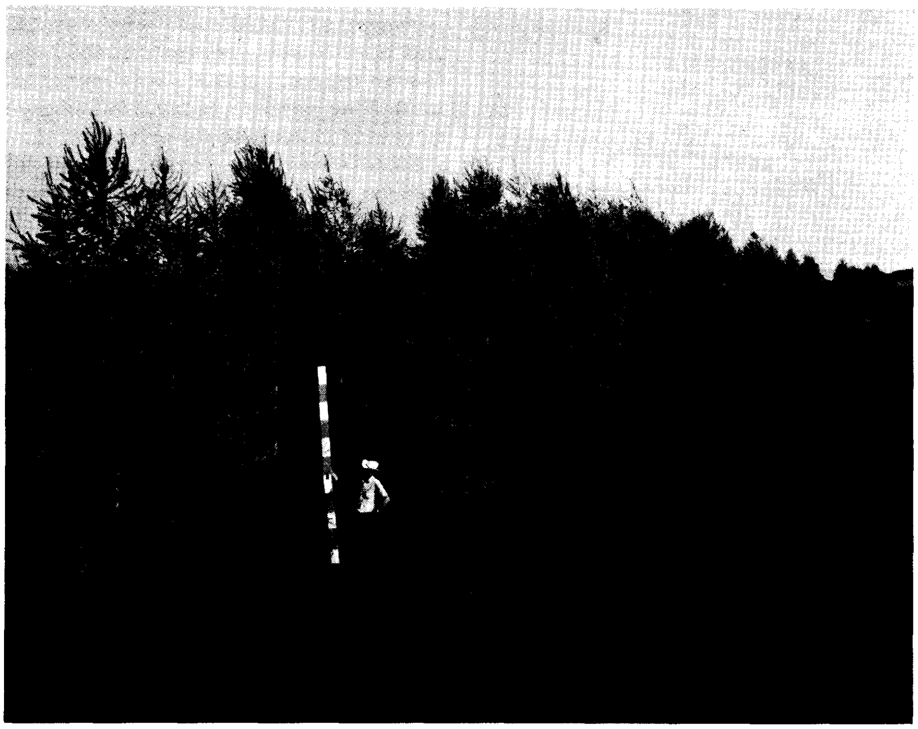

Figure 3. — View of Plantation 14—60 in Nebraska in the summer of 1969, 10 years after planting. The trees were generally of good form and grew faster than other conifers tested in the vicinity. One origin, unfortunately the slowest growing, fruited heavily in each of 5 years. (U. S. Forest Service Photo).

established trees in thrifty plantations from obscure causes.

Height. — Height data for the two nursery experiments can be summarised as follows:

Experiment	Height age 3	Range in provenance means	Degrees of freedom		F value for Provenance
			Provenance	Error	
	cm	*cm*			
7-origin	138	127—148	6	18	11.7**
22-origin	109	76—135	21	63	3.8**

** = significant at 1% level.

In the same nursery experiment, height at ages 1 and 2 was correlated strongly with height at age 3. The correlation between height at age 3 in the two experiments was calculated from the data for seven origins grown at both times. The correlation was significant at the 2% level (r = .80 with 5 d.f.).

A few plantations were measured at intervals of 1 to 2 years. In such cases the correlation between nursery height and height 1 to 2 years after field planting was high. But the correlations decreased as the plantations grew older. The lowest nursery-age 12 correlation was r = .2 for Nebraska plantation 14—60. The correlation was r = .58 between height at age 3 and at age 9 or 10 in four plantations of the 22-origin experiment.

Seven origins were represented in 18 plantations which were measured at ages 7 to 13. Their relative heights are presented in *Table 3*. An analysis of variance was calculated with the data in that table, using 6 and 112 degrees of freedom for seedlot and error (= plantation × seedlot interaction) respectively. The F value for seedlot was 8.75, showing that differences among seedlots were significant (1% level). For the region as a whole, seedlot 12 was the slowest growing and seedlots 15 and 24 were the fastest growing.

There were, however, statistically significant interactions between seedlots and plantations which are of great practical importance. Seedlot 15 was tallest at most test sites but shortest in Nebraska and Ohio. Seedlot 12 was short at most test sites, but tallest in Nebraska. Seedlot 22 grew slowly most places but was among the tallest at plantation 2—60 in southern Michigan. Some of the interaction were so extreme that we suspected mislabelling. However, the fruiting data indicate the interactions are real.

It is important to explain the interactions if possible. There was a tenuous relationship between relative height at different test sites and susceptibility to winter cold damage. In northern plantations, seedlots 15 and 16 grew relatively fast and suffered slight winter damage whereas seedlots 4 and 9 grew relatively slowly and suffered heavier winter damage. However, seedlot 24 does not conform to the pattern; it grew relatively fast and suffered relatively heavy winter damage in northern plantations. In view of the extremely tenuous relationships between growth rate and other measured traits, it is probably best to conclude that the interactions are not intelligible.

Hattemer (1969), working with Japanese larch in Germany, also concluded that his interactions were unintelligible. He subdivided his test sites in five different ways

Table 3. — Relative height of 7 Japanese larch seedlots grown at 18 locations in the north central states. The plantations are arranged in north-south order.

Plantation No. and Name	Relative height of seedlot No. 4	9	12	15	16	22	24	Actual mean height	Age from seed when measured
	percent of plantation mean							*meters*	*years*
17—60 Gunn Park MINN	98	105	93	97	103	101	102	6.87	13
22—60 Starks WIS	92	92	92	—	117	93	109	5.07	12
8—60 Ford MICH	102	—	91	—	129	68	107	3.94	13
10—60 Dunbar MICH	95	97	80	125	104	91	106	3.25	10
9—60 Benzie MICH	81	—	—	—	100	97	122	2.25	10
11—60 Manistee MICH	100	104	82	111	97	95	112	4.64	10
6—60 Rose Lake MICH	109	108	84	111	107	89	96	3.75	10
1—61 Kellogg MICH	110	101	87	115	88	104	96	2.68	9
2—60 Kellogg MICH	105	98	93	105	89	110	100	3.98	10
7—61 Russ MICH	92	98	92	103	91	96	130	3.78	9
15—60 Paint Creek IOWA	104	100	84	112	94	97	109	2.65	7
42—61 Sinnissippi ILL	113	88	76	112	121	80	110	3.05	10
49—61 Soap Creek IOWA	82	100	76	127	96	107	109	2.16	7
23—60 Purdue IND	95	110	81	121	100	86	116	3.86	9
20—60 Apple Creek OHIO	103	122	100	91	98	102	105	3.24	10
18—60 4-H Camp ILL	105	107	96	99	101	98	95	6.74	12
43—61 4-H Camp ILL	112	112	—	107	91	81	92	2.93	10
14—60 Horning NEB	101	106	106	83	95	104	105	7.41	12
Average relative height									
10 northern sites	98	100	88	110	103	94	108		
8 southern sites	102	106	88	106	99	94	105		
All sites	100	103	88	107	101	94	107		

and used factor analysis, but was unable to explain why particular seedlots grew relatively well some places, relatively slowly other places.

The 22-origin expriment was measured at five locations (*Table 4*). The error variances were higher than in the 7-origin experiment, and between-seedlot differences were statistically significant in only three of the plantations. An analysis of variance was combined on the combined data for the four plantations (1—61, 7—61, 42—61, 43—61) measured in 1967 or 1968, using 21 and 56 degrees of free-

Table 4. — Relative heights of 22 seed sources of Japanese larch in the Michigan nursery, five American and 18 German plantations (German data from Hattemer, 1969).

Origin No., Mountain of origin	Relative height at Mich. Nurs.	Kell. For. Mich. 1—61	Russ For. Mich. 7—61	Soap Creek Iowa 49—61	Sinn. For. Ill. 42—61	4-H Camp Ill. 43—61	Average relative height U. S.[1]	Germany
	percent of mean						*% of mean*	
1 Fuji	97	107	118	79	90	90	96	102
2 Fuji	95	111	110	107	98	125	109	103
4 Azusa	106	108	92	84	107	109	105	99
5 Yatsuga	110	107	114	87	97	81	105	109
6 Yatsuga	110	107	109	100	127	105	111	111
7 Yatsuga	116	109	99	95	97	96	103	109
8 Yatsuga	103	82	101	113	82	—	89	108
9 Yatsuga	124	99	98	101	98	99	98	108
10 Yatsuga	103	102	98	90	93	123	101	102
11 Akaishi	70	98	98	78	89	—	98	—
12 Akaishi	74	85	92	78	72	—	91	87
13 Nantai	114	96	103	107	106	115	103	105
14 Nantai	97	109	95	94	121	104	108	107
15 Nantai	117	113	103	129	106	104	108	106
16 Shirane	93	86	91	98	114	89	90	105
17 Asama	95	111	82	—	—	—	104	102
18 Asama	93	93	80	106	96	78	89	96
19 Asama	84	92	84	88	99	—	85	84
23 Komaga	86	93	95	130	—	—	103	104
22 Hida	110	108	96	109	75	78	103	99
24 Hida	99	94	130	111	104	90	102	97
25 Hida	105	102	112	115	97	83	98	97
Age, years	3	9	9	7	10	10	9—10	6
Actual mean, m	1.1	2.7	3.8	2.2	3.3	2.9	3.0	2.3

[1]) Weighted mean calculated with data from 1 to 10 plots each inplantations 1—61, 7—61, 42—61, 43—61.

dom for seedlot and error (= seedlot × plantation interaction) respectively. The F value of 2.02, although not high, was significant at the 2% level, indicating some consistency in height growth at all test sites.

There were significant correlations (1% level) in the 22-seedlot experiment among nursery height, height at ages 9 or 10 in four U. S. plantations and height at age 6 in 13 German plantations (data from HATTEMER, 1969). The correlations were as follow:

If correlation was between	Correlation coefficient was
Height at age 3 in Michigan nursery and height at age 9 or 10 in 4 U. S. plantations	r = .58
Height at age 3 in Michigan nursery and height at age 6 in 13 German plantations	r = .70
Height at age 9 or 10 in 4 U. S. plantations and height at age 6 in 13 German plantations	r = .57

Eight of the 22 seedlots in the second experiment grew at least 3% faster than average in both the German and U. S. plantations. Of these, three were from Mt. Nantai in the northeastern part of the species range, and three were from a small area on the Yatsuga Mountains.

Four parental stands (Nos. 15, 17, 19 and 22) were exceptionally slow growing. The offspring of stands 15 and 17 grew at above-average rates in Germany and the U. S. and the offspring of stand 22 grew at above-average rates in the U. S. Only stand 19 produced offspring which grew slowly in both countries. Evidently data on growth rate in Japan were of little value in forecasting growth rate in the United States or Germany.

Stem form. — Two types of stem deformities — fork and crook — were measured in five plantations. The forks were probably the result of winter dieback and were rare. There were one to four crooks per tree but most involved offsets of less than 1 cm and would be of little practical importance. The between-origin differences were not significant statistically in either trait, and for all practical purposes all origins were of acceptable form.

Time of growth initiation in the spring. — Japanese larch starts growth much earlier than do most northern conifers. Within a single plantation there were differences of 3 to 5 days within a tree (lower branches earliest), of 3 to 5 days among individual trees, and of 1 to 2 days among seed sources.

In the 7-origin experiment, earliness of growth initiation was measured at six locations in Michigan and Ohio. Although the measurement methods and accuracies varied, the results were consistent when reduced to standard terms. This consistency is shown in the following list in which the letters E, A and L denote "Early", "Average", and "Late" respectively at the six locations; No. 4 = LEEAEE, No. 9 — AEAAAA, No. 12 —— LLLLLL, No. 15 — LALLLL, No. 16 — EEAAEE, No. 22 — EEEEEE, No. 24 — EAAEEE. The means are given in *Table 5*.

In the 22-origin experiment, time of growth initiation was measured in two different years in two different Michigan plantations *(Table 6)*. In Michigan, as in Germany (data from HATTEMER, 1968), trees from Mts. Nantai and Akaishi were the earliest. The between-origin differences were significantly different (1% level) at Kellogg but not at Russ. The Kellogg-German correlation was significant (r = .64 with 20 d.f.) but the Kellogg-Russ (r = .32) and Russ-German (r = .12) correlations were not.

Spring frost damage. — Severe frosts can occur one month after the start of growth in the Lake States. Heavy frosts in successive years were partially responsible for the rapid decline of two Michigan plantations located in frost pockets.

Damage measurements were confined to rapidly growing plantations on good sites, where damage was heaviest on lower branches and caused some twig death or apparent loss of growth. Origins with little frost damage varied from shortest to tallest. Results were moderately consistent in three Wisconsin or Michigan plantations of the 7-origin experiment *(Table 5)*; correlations among plantations were .65, .60 and .59, significant at the 10% level. A May 1963 frost damaged the 22-origin plantation at Russ Forest *(Table 6)*. Of the between-origin variance, 72% was accounted for by differences among mountains of origin — origins from Mt. Nantai suffered the least damage. This was true also in New York (STAIRS, 1965) and Germany (HATTEMER, 1969).

The amount of frost damage was not correlated significantly with other measured traits, not even with time of growth initiation.

Summer foliage color. — In the nursery, the seedlots were slightly different in summer foliage color. When measured in any one year the between-origin differences were significant statistically (1 or 5% level). However, the differences were not consistent from year to year or from one experiment to the other.

Table 5. — Growth characteristics of seven Japanese larch origins represented in plantations established in 1960.

No.	Height age 10	Crooks /tree	Time of growth initiation	Damage by spring frost	Time of leaf fall	Damage by winter cold
	m	*No.*				
4	4.0	.3.0	Med.-early	Average	Late	Heavy
9	4.2	2.6	Average	Med.-light	Late	Heavy
12	3.7	2.4	Late	Heavy	Early	Average
15	4.1	2.1	Late	Light	Early	Light
16	4.0	2.9	Med.-early	Med.-light	Early	Light
22	3.9	2.5	Early	Heavy	Late	Heavy
24	4.2	2.6	Med.-early	Average	Average	Average
No. of plantations contributing data						
	7	2	4	3	5	3
Significance of between-origin differences						
	**	**	**	**	**	**

** = significant at 1% level.

Table 6. — Growth characteristics of 22 Japanese larch origins represented in plantations established in 1961

Origin No. and Mountain	Time of growth initiation	Damage by spring frost	Trees with flowers	Time of leaf fall	Damage by winter cold
	1 = early *10 = late*	*% of buds*	*%*		
1 Fuji	7[a]	51[b]	18[ab]	Late[abc]	Average[c]
2 Fuji	7	68	24	Late	Heavy
4 Azusa	9	62	1	Average	Heavy
5 Yatsuga	8	57	9	Average	Heavy
6 Yatsuga	9	59	4	Late	Average
7 Yatsuga	8	67	1	Late	Average
8 Yatsuga	6	54	5	Average	Heavy
9 Yatsuga	6	72	4	Late	Heavy
10 Yatsuga	7	70	1	Late	Heavy
11 Akaishi	4	68	16	Late	Heavy
12 Akaishi	1	76	1	Late	Average
13 Nantai	1	19	6	Early	Average
14 Nantai	5	49	4	Early	Light
15 Nantai	4	49	7	Early	Light
16 Shirane	8	56	5	Early	Light
17 Asama	8	67	8	Early	Light
18 Asama	6	56	27	Average	Heavy
19 Asama	6	48	13	Average	Light
23 Komaga	7	55	4	Average	Heavy
22 Hida	9	76	1	Average	Heavy
24 Hida	10	62	3	Average	Heavy
25 Hida	7	59	5	Early	Light
No. of plantations contributing data					
	1	1	2	3	1
Significance of between-origin differences					
	**	**	**	None	**

** = significant at 1% level.
a, b, c = data from plantation 1—61, 2—61 or nursery respectively.

Autumnal color change and winter injury. — In autumn the leaves change from green to yellow to brown, then drop. Trees differ by a few days in the time at which the color change occurs, but not in depth of color. Origins differ from each other by two to three days. This characteristic was measured (annually in the nursery and once in each of seven plantations) as the percentage of yellow leaves per tree on a particular date.

While the trees remained in the nursery they suffered slight winter dieback, presumably because of cold damage. At the most, 20 cm of the leader died. The trees grew hardier as they grew older, and damage was nil in all except one Wisconsin plantation.

In the 7-origin experiment the results on date of leaf fall were consistent from nursery to plantation and among plantations. Also, there were statistically significant (1% level) correlations between time of leaf fall and amount of winter dieback. Origins which lost their leaves earliest formed dormant buds earliest and suffered the least winter damage.

This same correlation was evident, but much weaker, in the 22-origin experiment *(Table 6)*. Origins which lost their leaves early suffered either light or medium winter damage. There was a regional pattern to the variation (F values for differences among mountains significant at 1% level) to the variation. Origins from Mt. Nantai, Mt. Shirane and Mt. Asama dropped their leaves earliest and suffered the least winter dieback. In German laboratory experiments (Schönbach *et al.*, 1966), trees from Mt. Fuji were most susceptible to winter cold.

According to the nursery data for both experiments there was a significant (1% level) correlation between date of leaf fall in Michigan and in Germany. The correlation was the strongest found for any trait.

Flowering and cone production. — Production of female flowers started at age 5 from seed. By age 12, more than 3,000 cones had been produced in the 7-origin experiment. There were pronounced between-origin differences in cone production, as indicated by the following:

Origin 15 produced 78 percent of the cones,
Origin 9 produced 17 percent of the cones,
Origins 4, 12, 16, 22 and 24 produced only 5 percent of the cones.

There were also pronounced between-plantation differences; more than 94 percent of the cones were produced on four plantations (10—60 and 11—60 in Michigan; 14—60 in Nebraska; 22—60 in Wisconsin).

There was also pronounced plantation × genotype interaction in cone production. In plantation 14—60 (Neb.), origin 15 produced 1,120 cones over a 4-year period and other origins produced only 6 cones. In plantation 10—60 (Mich.), origin 15 produced 1,090 cones, origin 9 produced 265 cones, other origins produced 100 cones in the 10th year from seed. In plantation 22—60, origin 9 produced 150 cones and other origins (No. 15 was not present) produced no cones at age 7 from seed. In each of these cases flowering occurred on several trees of the fruitful sources in each plantation. The data on percentages of trees producing cones *(Table 7)* illustrate these trends, but somewhat less dramatically than the data for numbers of cones.

Table 7. — Percentage of fruiting trees in seven origins of Japanese larch planted at 13 locations in north central U. S. No flowers were observed at five other plantations.

Plantation	Percentage of trees with cones in source No.							Age from seed when cones were observed
	4	9	12	15	16	22	24	
22—60 Starks WIS	0	40	0	—	0	0	0	7, 10
8—60 Ford MICH	7	—	0	—	0	0	0	13
10—60 Dunbar MICH	0	58	5	55	11	6	0	10
9—60 Benzie MICH	0	—	—	—	3	4	0	5, 10
11—60 Manistee MICH	0	3	0	0	0	0	3	10
6—60 Rose Lake MICH	0	0	0	4	0	0	0	10, 11
1—61 Kellogg MICH	2	0	0	7	0	0	0	8
2—60 Kellogg MICH	0	0	0	30	0	0	0	10
7—61 Russ MICH	0	38	0	0	0	0	0	8
15—60 Paint Creek IOWA	10	15	15	2	2	2	2	7
23—60 Purdue IND	0	3	0	0	0	0	0	7, 9
20—60 Apple Creek OHIO	32	33	60	0	12	27	0	11
14—60 Horning NEB	4	4	0	40	0	2	0	6, 7, 8, 9, 10, 12

In the 22-origin experiment there was evidence of a geographic variation pattern *(Table 6)*. Female flowering was heaviest on trees from Mt. Fuji (southwestern part of range) and Mt. Asama (north central part of range).

There were fewer data on male flower production, which started at age 10 in two of the most vigorous plantations. At Russ Forest, Michigan, pollen production was heaviest on those origins producing the most female flowers. At Nebraska plantation 14—60, pollen production was moderate on all origins.

Attempts to explain the flowering behavior in terms of growth rate or other growth characters failed. For example, flowering was heaviest on the shortest seedlot in Nebraska plantation 14—60 and Wisconsin plantation 22—60, but on the tallest seedlots in Michigan plantations 6—60 and 10—60.

Insect Damage. — In 1965 a heavy infestation of larch sawfly *(Pristiphora erichsoni* [Htg.]) occurred near plantation 10—60 in northern Michigan, attacking nearly all the tamarack in the vicinity and a small percentage of the Japanese larch. In 1969, larch case bearer *(Coleophora laricella* [Hbn.]) attacked Ohio plantation 20—60, causing moderate to heavy damage. In both cases the differences among origins were statistically significant (5% level for sawfly, 1% level for larch case bearer). The amount of damage by seed origin is shown below.

Insect, unit of measure	Damage to Origin No.						
	4	9	12	15	16	22	24
Larch sawfly, % of trees attacked	0	3	3	18	8	5	3
Larch case bearer, grade 1 = none, grade 5 = heavy attack	2·7	2.0	2.7	1.4	2.0	1.8	3.2

There appears to be no relationship between attack by the two insects.

Interpretation of the Geographic Variation Pattern

Some regional trends can be noted in the data included in *Tables 4 and 6*. As compared with the majority of the progenies:

Trees from Mt. Nantai were exceptionally tall, started growth early and were least damaged by late spring frost, dropped their leaves early and suffered relatively little damage from winter cold;

Trees from Mt. Asama were exceptionally short but fruited heavily;

Trees from Mt. Fuji fruited heavily, kept their leaves late in the autumn and suffered heavy winter damage.

In Germany, also, there were some regional trends. Hattemer (1968) reported that the following traits varied significantly among mountains:

Height at ages 2 and 3 (but not at ages 4 and 5) (tallest trees from Mt. Nantai, shortest from Mts. Akaishi, Asama, Komaga, Hida)

Branch weight as a percent of total plant weight at age 5 (Highest in trees from Mts. Komaga and Hida, lowest in trees from Mts. Fuji, Akaishi, Nantai)

Wood density at age 5 (low in trees from Mts. Akaishi and Asama)

Late-spring frost damage at age 8 (low in trees from Mt. Nantai)

For these traits the differences among mountains accounted for 50 to 75% of the between-origin variance; for another 15 traits, the differences among mountains were not significant statistically.

The climates are generally moister on Mt. Nantai and colder on Mt. Asama than in other parts of the range *(Table 1)*. Thus in a trait such as growth rate (high for Mt. Nantai, low for Mt. Asama), correlation analyses are apt to show the presence of significant positive correlations between height and temperature at place of origin, and of negative correlations between height and precipitation at place of origin. Hattemer (1969) analyzed his 6-year height and 9-year diameter data for each of 13 plantations, and found such relations. The correlations were significant (and accounted for 25 to 50 percent of between-origin variance) for four plantations; they were not significant (5% level) and accounted for less than 20% of between-origin variance for nine plantations.

In neither the American nor the German data were there significant elevational, temperature nor precipitation trends within single mountains or mountain ranges.

The regional trends are much less clearcut than in more widely distributed species such as Scotch pine *(Pinus sylvestris* L.) or Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco. Also, the correlations between climate at place of origin and performance are too weak to indicate strong cause-and-effect relationships. It is not wise to speak of either distinct races or well-developed clines.

Perhaps it is best to ascribe most of the variation to genetic drift, which has caused the populations of some entire mountains to become a little different from the rest of the species in some traits and which has resulted in as much variation within as between mountains in other traits. Such an interpretation is consistent with the amount of genetic variation (small compared with that found in more widely distributed species), the range of the selection pressures (also small compared with those found in more widely distributed species), and with the small size and isolation of the Japanese larch populations.

Practical Recommendations

Differences in growth rate among seed origins were large whereas differences in other traits were of little practical significance. Therefore, only growth rate need be considered in making practical recommendations. One seedlot, No. 6, grew most rapidly in Germany and the north central states; in Germany it produced 70% more wood per tree than the experiment average. A few others were nearly as good.

The fastest growing seedlots were from Mts. Fuji, Yatsuga and Nantai. However, Mt. Yatsuga also yielded seedlots which grew slowly in German plantations. Hence it is desirable to use data such as contained in *Tables 3 and 4* and specify specific stands when ordering seed. There were no consistent relationships between growth rate in the north central states and elevation, soil type or temperature at the place of origin. Therefore nothing is to be gained by specifying that seed be collected from a particular elevational or temperature zone.

Some interactions should be considered. For example, source 15, which grew rapidly at most places, grew slowly in Ohio and Nebraska. Source 24, which grew rapidly in most plantations, grew slowly at four locations in Michigan and Illinois. However, we do not know the cause of the interactions and therefore can not forecast when a particular seedlot will deviate significantly from its average performance. Hence, it is possible that recommendations should be based only on average performance at many test sites.

If seed orchards in the north central states are contemplated, flowering data must be considered. Unfortunately there are conflicts between the flowering and growth data. For example, a seed orchard based upon origin 15 could produce much good seed by age 10 at a number of localities. Such seed would be recommended for commercial use in Michigan, Indiana and Iowa, but would definitely not be recommended for Nebraska. It appears that Nebraska must continue to depend on Japanese seed sources or spend a longer time bringing seed orchards into bearing.

Summary

Data on 9- to 13-year performance are presented for a 7-origin provenance test planted at 13 locations in eight states and for a 22-origin (including the first 7) provenance test planted at five locations in three states. Correlations were moderate between the two experiments, also between data gathered in north central plantations and 13 plantations in Germany. There were significant between-origin differences in stem form, time of growth initiation, damage by spring frosts, time of leaf fall, damage by winter cold and by two insects, but such differences were of minor practical significance compared with the 25 percent differences in growth rate between the fastest and slowest growing origins. Correlations between time of leaf fall and damage by winter cold were strong, but other intercharacter correlations were not. The variation in some traits followed a weak geographic pattern, trees from Mts. Asama and Nantai being the most exceptional. There were strong genetic differences as well as strong genotype-plantation interactions in production of female flowers.

Zusammenfassung

9- bis 13jährige Untersuchungsergebnisse von einem Provenienzversuch mit 7 Herkünften an 13 Orten in 8 Staaten und einem Provenienzversuch mit 22 Herkünften (einschl. der ersten 7) an 5 Orten in 3 Staaten werden besprochen. Die gefundenen Korrelationen bei den beiden Versuchen und den aufgenommenen Daten bei den Versuchen in den Nord-Zentral-Staaten sowie denen in den 13 Versuchen in Deutschland waren mäßig. Es fanden sich signifikante Unterschiede zwischen den Herkünften in der Stammform, im Zeitpunkt des Wachstumsbeginns, bei den Schäden durch Frühjahrsfröste, im Zeitpunkt des Nadelabfalles, bei den Schäden durch die Winterkälte und solchen, die durch 2 Insekten verursacht wurden. Diese Unterschiede waren, gemessen an 25%igen Unterschieden in der Wachstumsrate zwischen den Herkünften, jedoch nur von untergeordneter Bedeutung. Die Korrelationen zwischen den Daten des Nadelabfalles und denen der Schäden durch die Winterkälte waren stark ausgeprägt. Andere derartige Korrelationen gab es aber nicht. Die Variation mancher Merkmale entsprach etwas der der geographischen Herkunft. Die Bäume von den Asama- und Nantai-Bergen waren dabei am außergewöhnlichsten. Es fanden sich auch genetische Unterschiede und starke Interaktionen zwischen Genotypen und Pflanzort bei der Produktion weiblicher Blüten.

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