USDA FOREST SERVICE
RESEARCH PAPER **NC-190**

1980

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Riemenschneider, Don E., and R. M. Jeffers.

1980. Height and diameter growth of tamarack seed sources in northern Wisconsin. U.S. Department of Agriculture Forest Service, Research Paper NC-190, 6 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Reports height and diameter growth of tamarack seed sources planted in northern Wisconsin and makes recommendations for selecting the highest-yielding sources.

KEY WORDS: *Larix laricina*, seed source test, planting recommendations.

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Manuscript approved for publication August 7, 1979

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HEIGHT AND DIAMETER OF TAMARACK SEED SOURCES IN NORTHERN WISCONSIN

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Tamarack (*Larix laricina* (DuRoi) K. Koch) is one of the most widely distributed North American conifer species. It will grow under a wide range of climatic conditions and site characteristics and is one of the fastest growing boreal conifers on well-drained sites (Roe 1957). Although it accounts for a small proportion of pulpwood production in the Lake States (Blyth and Hahn 1974), harvesting is increasing (Johnston 1975). Recent investigations have been designed to evaluate genetic variation (Pauley 1965, Jeffers 1975, Sajdak 1970, Cech *et al.* 1977) and the potential for short rotation intensive culture (Zavitkovski and Dawson 1978).

This paper presents survival, height, and diameter data for 13- and 14-year-old trees in a seed source test of tamarack. The investigation is part of a cooperative study of rangewide variation in tamarack begun by the University of Minnesota (Pauley 1965). Earlier height and survival data have been reported by Jeffers (1975).

MATERIALS AND METHODS

Two experimental plantings were established on old field sites in north-central Wisconsin in October 1967. The planting sites and experimental design have been previously described (Jeffers 1975).

One planting consists of 24 seed sources and is located on a well-drained, high quality tamarack site in Forest County (table 1) (Jeffers 1975). The other planting is in Oneida County and includes 17 of the same seed sources. In both cases, a few seed sources were planted as 2-2 transplants but the majority were planted as 3-0 seedlings. A randomized complete block design with 10 replicates and 4-tree row plots was used at both locations.

All trees were measured in November 1977 for total height and diameter at breast height. Data were subjected to analysis of variance with plot means as entries. Variation among sources was then partitioned to determine if significant differences existed between age groups and between sources within each age group. The relation between seed source performance and the latitude and longitude of origin was examined using linear and curvilinear regression models. Relations among variables were tested by simple correlation analysis.

RESULTS

Survival

Mean survival for 13- and 14-year-old trees at the Forest County site was 76 percent and 91 percent, respectively (table 1). Most of the losses occurred in the first 2 years after planting (Jeffers 1975). Analysis of variance showed significant differences in survival between age groups and among 13-year-old sources but not among 14-year-old sources (table 2).

Mean survival for 13- and 14-year-old trees at the Oneida County site was 60 percent, which is considerably less than the survival at the Forest County site (table 1). Mortality did not drop off after 2 years like it did at the Forest County site.

Table 1.—*Origin, survival, height, and diameter of tamarack seed sources*

Age	Source no.	State or Province	County	°N Latitude	°W Longitude	Forest County Survival	Forest County Height	Forest County D.b.h.	Oneida County Survival	Oneida County Height	Oneida County D.b.h.
						Percent	*m*	*cm*	*Percent*	*m*	*cm*
14	3036	ME	Somerset	45.7	71.2	88	6.36	8.28			
	3019	WI	EauClaire	44.7	91.0	98	5.51	6.79	68	4.85	6.75
	3014	MN	Anoka	45.1	93.0	100	5.43	6.57	72	4.76	6.05
	3007	WI	Washburn	46.0	91.8	90	5.41	6.55			
	3038	MI	VanBuren	42.2	86.1	90	5.18	5.82	60	4.36	5.32
	3011	WI	Waukesha	43.0	88.2	82	5.16	5.67	45	4.68	5.50
					Average	91	5.51	6.61	61	4.66	5.90
13	3333	NS	Annapolis	44.8	65.0	75	5.05	5.61	80	4.86	5.89
	3319	MN	Anoka	45.2	93.1	52	5.04	5.66	42	3.63	3.96
	3266	WI	Oneida	45.8	89.2	90	4.96	5.43			
	3330	ME	Somerset	45.6	70.3	85	5.02	5.80	72	4.40	5.29
	3282	WI	LaCrosse	43.8	91.1	80	5.02	5.67	45	4.59	5.61
	3265	WI	Forest	45.8	88.9	88	4.94	5.54	58	4.13	4.50
	3323	WI	Trempaleau	44.2	91.5	80	4.89	5.18			
	3332	ONT	Oxford	43.2	80.6	62	4.81	5.69	72	4.58	5.24
	3284	MN	Itasca	47.4	93.6	85	4.76	5.14	52	4.19	5.13
	3272	MI	Alger	46.5	87.0	82	4.72	5.16			
	3283	MN	Itasca	47.5	94.1	95	4.61	4.85	65	4.10	4.57
	3320	MN	St.Louis	47.0	93.0	80	4.55	4.91	65	3.94	4.37
	3324	MAN		50.1	95.4	90	4.55	4.64	60	4.16	5.30
	3327	MI	Chippewa	46.3	84.2	55	4.55	4.99	58	4.94	6.14
	3331	MI	Houghton	47.0	88.4	78	4.40	4.69	45	3.83	4.30
	3273	MI	Alger	46.5	87.0	68	4.35	4.81	58	3.86	4.73
	3337	MI	Ingham	42.5	84.8	62	3.66	3.48			
	3332	ATA		56.6	111.2	68	3.04	3.08			
					Average	76	4.61	5.02	59	4.25	5.00
			Least significant difference			18	0.61	0.93	25	0.55	0.85

Table 2.—*Mean squares for survival, height, and diameter of tamarack seed source*

Mean square	Forest County df	Forest County Survival	Forest County Height	Forest County Diameter	Oneida County df	Oneida County Survival	Oneida County Height	Oneida County Diameter
Among sources	23	[1]2.674	[1]3.988	[1]10.728	16	[2]2.031	[1]1.624	[1]5.862
Between age groups	1	[1]32.289	[1]36.453	[1]113.128	1	[2]0.163	[1]4.370	[1]26.888
Among 14-year-old sources	5	[2]0.670	11.984	[1]8.783	3	[2]2.300	[2]0.383	[1]4.280
Among 13-year-old sources	17	[1]1.404	[1]2.668	[1]5.276	12	[2]1.119	[1]1.706	[1]4.503
Error	205	0.678	0.482	1.130	129	1.293	0.392	0.947

[1]Significant at $P < 0.01$.
[2]Not significant.

Height

Mean height at Forest County was 5.51 m for 14-year-old trees and 4.61 m for 13-year-old trees. All components of variation between and within sources were significant (table 2). The mean of the shortest 14-year-old trees (Source 3011, Waukesha County, WI) was greater than the mean of the tallest 13-year-old trees (Source 3333, Annapolis County, Nova Scotia). The tallest trees in both age groups were from Wisconsin, central Minnesota, Maine, and Nova Scotia. However, trees from Source 3319 from Anoka County, Minnesota, have shown susceptibility to snow damage (Sajdak 1970, Jeffers 1975). The shortest trees were from Michigan, northern Minnesota, and northwestern Canada.

Mean height at Oneida County was 4.66 m for 14-year-old trees and 4.25 m for 13-year-old trees (10 percent less than at Forest County). Differences were significant between age groups and among sources of 13-year-old trees but not among sources of 14-year-old trees. The tallest 13-year-old trees were from Chippewa County, Michigan, and Annapolis County, Nova Scotia. Source 3319 from Anoka County, Minnesota, was the poorest source at Oneida County and was one of the best sources at Forest County.

Diameter

Results for this variable were similar to those for total height. The most notable difference was that the range of seed source means was greater than for height (96 percent of the mean for d.b.h. vs. 69 percent for height at Forest County and 54 percent vs. 28 percent at Oneida County). Mean d.b.h. at Forest County was 6.61 cm for 14-year-old trees and 5.02 cm for 13-year-old trees. Age groups overlapped somewhat. Fourteen-year-old trees from Source 3011 had a mean d.b.h. of 5.67 cm while 13-year-old trees from Source 3330 had a mean d.b.h. of 5.80 cm. The tallest trees also had the largest diameters.

Differences were also significant between age groups and among sources within age groups in Oneida County. Again, sources that ranked high in height also ranked high in diameter. The poorest source once more was 3319 from Anoka County, Minnesota.

Correlation and Regression Analyses

Simple correlation analysis was performed between all variables measured in this study at ages 13 and 14 and also the 8- and 9-year heights presented by Jeffers (1975) (table 3). The age-age correlation for total height was remarkably high—0.92 at the Forest County site and 0.81 at the Oneida County site. The height-diameter correlations were 0.98 at Forest County and 0.93 at Oneida County. The correlation between seed source means at different sites was 0.55 for height and 0.59 for d.b.h.

Height and diameter at the Forest County planting were significantly and negatively correlated with

Table 3.—*Simple correlations*

	1	2	3	4	5	6	7	8
Forest County								
7,8-year height								
13,14-year survival	[1,2]0.58							
13,14-year height	[1].92	[3]0.49						
13,14-year d.b.h.	[1].93	[3].45	[1]0.98					
Oneida County								
7,8-year height	[1].82	[4].42	[1].62	[1]0.85				
13,14-year survival	[4].06	[4].29	[4].22	[4].31	[4]0.39			
13,14-year height	[4].47	[4].17	[3].55	[3].56	[1].81	[4]0.45		
13,14-year d.b.h.	[3].57	[4].28	[3].58	[3].59	[1].86	[4].15	[1]0.93	
Source latitude			[1]−.54	[3]−.46			[4]−.44	[4]−0.30
Source longitude			[3]−.49	[3]−.47			[4]−.40	[4].26

[1]Significant at $P < 0.01$.
[2]df = 22 for Forest County; 15 for Oneida County; 15 between sources common to both locations.
[3]Significant at $P < 0.05$.
[4]Not significant.

latitude and longitude of the source origin. The effect of latitude is easily interpreted as a photoperiod controlled adaptation to environmental gradients, but the effect of longitude is not as easily understood. It should be noted that latitude and longitude were significantly correlated ($r = 0.56$), i.e., the collections ranged from northwestern Canada to the eastern United States, suggesting that the relation between growth and longitude of seed source may be spurious. Partial correlation analysis did not provide an answer to this question.

The effect of latitude of origin on tree height at the Forest County site was also investigated via linear regression of seed source mean height on latitude of origin for the 18 sources of 13-year-old trees. The regression ($P < 0.025$) accounted for 38 percent of the variation in height (fig. 1). There was a response gradient of 2 percent of the experiment mean per degree of latitude with trees of more northern latitudes performing poorly. An examination of raw data and standardized residuals indicated, however, that they departed from the linear model. Two sources from north and south of the planting site (3332 and 3337) were found to lie more than two standard deviations below the regression line. Although a third degree polynominal model accounted for 69 percent of the variation, the cubic independent variable was on the borderline of significance ($P < 0.10$) and the relation was not investigated further.

DISCUSSION

Seed sources of tamarack differed significantly in survival, height, and diameter at two sites in north-central Wisconsin. The presence of significant differences tended to depend on the age group of the trees and the site on which they were grown—more differences existed among seed sources on the better site and among seed sources of the younger trees. However, this may be a result of differences in precision due to the unequal numbers of sources in the two age groups.

The site with the best survival and growth was a well-drained upland site adjacent to a stand of natural tamarack (Jeffers 1975). The best trees at this location were from Wisconsin, central Minnesota, Maine, and Nova Scotia. In other cooperative tests, a source from Clare County, Michigan, was tallest

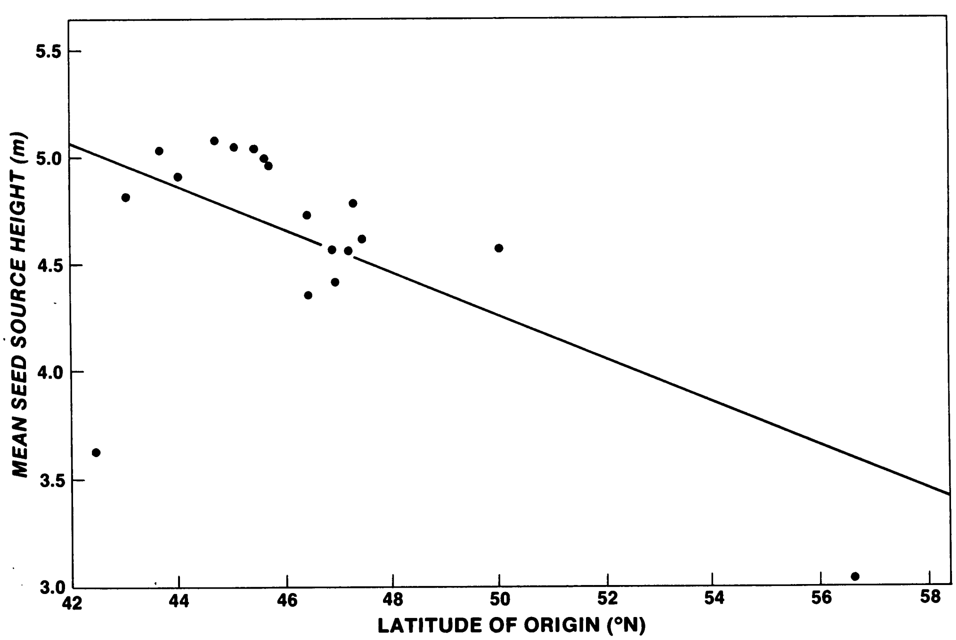

Figure 1.—*The regression of mean height on latitude of origin for 18 sources of 13-year-old tamarack. The regression equation is height = 9.43 − .10 (°N Latitude).*

(Sajdak 1970, Cech *et al.* 1977). This source was not represented in the Wisconsin tests, but sources from similar latitudes (3282 and 3323) ranked high.

Due to the limited nature of the experimental population, no estimate of genotype × environment interaction was made. Some inference, however, can be made on the basis of seed source rank and correlations. The correlations between sites were 0.55 for height and 0.59 for d.b.h. (r^2 = 0.30 and 0.35). Although the correlations are significant ($P < 0.01$), they are not extremely high values and reflect a lack of consistent performance over the two sites. An examination of seed source means shows that sources 3319 (Anoka County, Minnesota) and 3327 (Chippewa County, Michigan) are extremely unstable in this experiment (fig. 2). The reason for this instability remains unknown however, because the two sources do behave erratically, they may not be suited to planting in north-central Wisconsin.

Due to the strong age-age and height-diameter correlations, there appears to be no reason to modify the following seed source recommendations for north-central Wisconsin (Jeffers 1975):

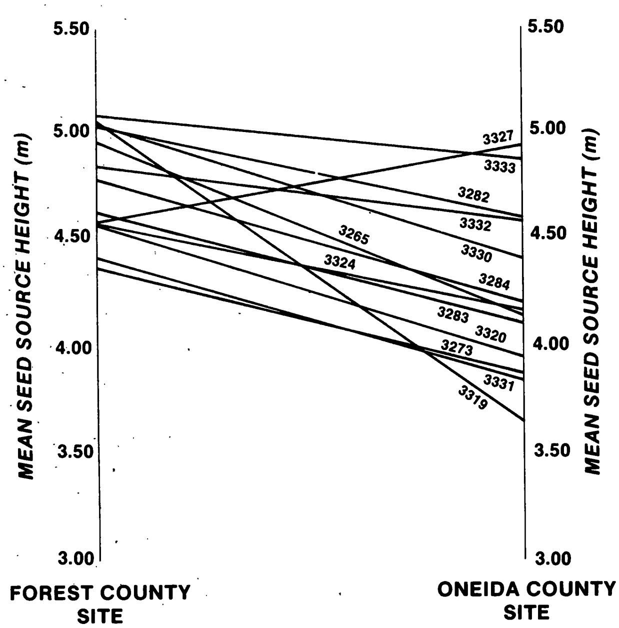

Figure 2.—*Height of 13-year-old trees from 13 sources of tamarack at two locations in northern Wisconsin.*

1. Maine, Somerset County (3036 and 3330)
2. Wisconsin, Eau Claire County (3019)
   LaCrosse County (3282)
   Oneida County (3266)
3. Nova Scotia, Annapolis County (3333)

These sources are those that grew best on the highest yeilding site and also appeared to have reasonably stable performance. Although collections from the original stands represented in this study may be the best approach to seed procurement, the curvilinear regression of mean seed source height on latitude of origin indicates that there may be a range (43.5°N to 46.0°N) where high performing genotypes can be found. However, because one of the sources that lead to the fitting of a polynominal model is present at only one location and a source with known instability (3319) is included in the latitudinal range, there may be some risk associated with such a generalization.

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☆ U.S. Government Printing Office: 1981—766-505/135 Region No. 6