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Twenty-year results of the Lake States JACK PINE seed source study

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TWENTY-YEAR RESULTS OF THE LAKE STATES JACK PINE SEED SOURCE STUDY

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Jack pine (*Pinus banksiana* Lamb.) is an important pulpwood species in the Lake States. It grows under a wide variety of environmental conditions and exhibits considerable phenotypic variation both within and among stands. Knowledge of genetic variation in this species is basic to a jack pine tree improvement program for the Lake States.

In 1951 the North Central (then the Lake States) Forest Experiment Station and the University of Minnesota began a regional seed source study to determine the nature and extent of genetic variation in jack pine. Private, State, and Federal forestry agencies collected seed from 29 natural stands in Minnesota, Wisconsin, and Michigan. Seedlings produced from those seed collections were planted at 17 locations in the three Lake States and at a single location in Ontario.

This paper includes data on survival, total height, diameter, volume per tree, and volume per acre 20 years after planting at 14 locations in the Lake States.

LITERATURE REVIEW

Results of plantings at one or more locations have already been published by various cooperators.

Stoeckeler and Rudolf (1956) reported on height growth at age 2 and change in needle color in fall at ages 1, 2, and 3 at the Hugo Sauer Nursery at Rhinelander, Wisconsin. Changes in fall needle color were found to be associated with latitude of seed source (the more northerly the seed source the more purplish the needles). Height growth of 2-0 stock was negatively correlated with latitude of seed source and positively correlated with normal annual sum of average daily temperatures of 50°F or above (growing degree days) at seed origin.

Arend *et al.* (1961) reported on 5-year results in three Lower Michigan plantations. Tree height differences among seed sources were significant at all three locations.

Survival and height growth 5 years after planting were also reported at six locations in Minnesota by Jensen *et al.* (1960), but statistical analyses were not included.

Alm *et al.* (1966) found highly signifcant differences among seed sources in height and diameter growth after 9 years in a plantation at the University of Minnesota Cloquet Forestry Center in Carlton County, Minnesota.

King (1966) reported on 10-year height growth of trees from 26 sources common to 11 plantings in Minnesota, Wisconsin, and Michigan and from a local commercial seed source (different at each location). At 10 locations there were significant differences in total tree height among test seed sources. At almost all locations test seed sources from nearest the planting sites outgrew the commercial nursery stock. King concluded that selection of "good" jack pine stands for seed collection appears worthwhile in the species, but selection of tested nonlocal stock may offer even greater improvement.

Utilizing the data reported by King (1966) and data from the Ontario planting, Morgenstern and Teich (1969) reported increases in height were obtained by planting trees 2 to 3° north of their seed origin.

Rudolph (1964) described variation among trees from different seed sources in lammas growth and prolepsis in four Minnesota and two Wisconsin plantings. He found significant differences in these traits among 30 seed sources in the Cloquet plantation and significant differences among 10 widely distributed seed sources evaluated at all locations.

Variation among seed sources in susceptibility to several insects and diseases has been found in several of the plantings. Batzer (1961, 1962) found significant differences among sources in incidence of white pine weevil (*Pissodes strobi* (Peck)) in two northern Minnesota plantings.

Arend *et al.* (1961) evaluated three plantings in Lower Michigan after 5 years and found significant differences among seed sources in incidence of white pine weevil, bark beetles (*Pityophthorus* spp.), and redheaded pine sawfly (*Neodiprion lecontei* (Fitch)), but no significant differences among sources in eastern gall rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai) incidence.

King (1971) reported on variation among seed sources in incidence of white pine weevil, eastern pineshoot borer (*Eucosma gloriola* Heinrich), and eastern gall rust at 11 locations in Minnesota, Wisconsin, and Michigan. He found significant differences among sources in white pine weevil incidence, and concluded that Lower Michigan sources are the best to use as a starting point in a white pine weevil resistance breeding program.

Eastern pineshoot borer was found in eight of the 11 plantations evaluated after 5 years, but no significant differences among sources in borer incidence could be shown. However, after 10 growing seasons in the field, there were significant differences among seed sources in borer incidence in two Wisconsin and one Upper Michigan plantings.

King found eastern gall rust after 10 years in every plantation he examined. In seven plantations in which more than 15 percent of the trees were infected, differences among seed sources in gall rust incidence were significant.

Trees from the northernmost sources showed high rust incidence while those from southern sources had the lowest rust incidence. King suggested that trees from the sourthern portion of the range have been subjected to more intense gall rust infection, and have developed some resistance to it, while those from farther north, where the alternate hosts are not as abundant, have not been subjected to as severe a selection for resistance.

King and Nienstaedt (1965) described variation among seed sources in needlecast (*Davisomycella (Hypodermella) ampla* (Dav.) Dank) incidence in a western Upper Michigan and a southern Wisconsin plantation. They found significant differences among sources in susceptibility to the needlecast fungus at both locations, indicating that susceptibility to this disease is under direct genetic control.

Information published to date has given considerable insight into the development of this study. Significant differences among seed sources have been found for several traits, including height and diameter growth, lammas growth and prolepsis, and pest incidence. Variation among seed sources in most traits appears to be clinal, and individual genotypes react strongly to different test environments. Northern and southern sources contribute most to this interaction, while middle-latitude sources contribute little.

Yeatman (1974) showed that tree height at 5 years was ineffective in predicting tree height at 19 years for 12 Ontario seed sources grown at the Petawawa Forest Experiment Station. Variation in tree height at 11 years, however, was very effective in predicting height at 19 years and provided a sound basis for selection of the better seed sources. King's (1966) data and our data on Lake States jack pine substantiate Yeatman's results.

METHODS

Seed Sources and Plantation Establishment

In 1951 and early 1952 seed was collected from 29 jack pine stands in Minnesota, Wisconsin, and Michigan. Each collection was made from dominant and codominant trees in a stand considered good for its locality.

Seed from all 29 stand collections was sown in the spring of 1952 in both the General Andrews State Nursery at Willow River, Minnesota, and in the Hugo Sauer State Nursery at Rhinelander, Wisconsin.

Two-year-old seedlings were planted by nine cooperating agencies at 17 locations, one in the fall of 1953 and 16 in the spring of 1954. Seedlings produced at the Genral Andrews Nursery were used to establish six plantations in Minnesota and two plantations in western Wisconsin. Seedlings produced at the Hugo Sauer Nursery were used to establish four additional plantings in Wisconsin and five plantations in Michigan.

At each location a randomized complete-block design with four replications was used. Each source was represented in each replication by a square 64-tree plot with trees planted at a spacing of 5 × 5 feet. In addition to the selected seed sources, each replication contained one seedlot of stock supplied by a commercial nursery in the same area as the test plantation. Very little is known about the origin of the commercial stock in many instances.

Because of shortages of seedlings from a few sources, substitutions were made at several locations. Data for 26 seed sources (table 1, fig. 1) common to 14 locations[1] (fig. 1, table 2) are presented here.

Measurements

Survival, height, and diameter

In the fall of 1973, 20 years after establishment, the trees were evaluated for survival, total height, and diameter. Survival data are based on the 64 trees originally planted in each plot.

To save time and expense in tree measurement, a statistical sample was selected from each plantation. The sample was based on variances obtained with the 10-year measurements of height and d.b.h. plus an assumption that means and their standard errors would increase about in the same proportion between 10 and 20 years, which proved valid. We first determined that measuring trees on all four replications was the best procedure. To determine number of trees to be measured per plot, an estimate of the standard error of a source mean was plotted against number of trees measured per plot for both height and d.b.h. The standard error increased slowly as the number of trees measured decreased from 64 to about 15, and increased more rapidly as numbers were reduced further. The proportional increase in standard error between measurement of 15 and eight trees per plot was 17 percent for height and 24 percent for d.b.h., and the decrease in number of trees measured was 47 percent. The standard error increased more rapidly as sample size decreased further. Taking costs and estimated standard errors into account, we

[1]*One source planted at 13 locations only.*

Table 1.—*Jack pine seed source origins*[1]

Seed source	County	Latitude	Longitude	Growing degree days[2]	Average January temperature
		°N	°W		°F
MINNESOTA					
1589	Cass	47.4	94.4	9,200	5
1590	Cass	47.0	94.6	9,400	7
1591	Itasca	47.5	94.1	9,100	5
1592	Lake	47.7	91.2	7,400	10
1593	Cook	48.0	90.3	6,700	14
1594	St. Louis	48.1	92.4	8,500	5
1595	Pine	46.0	92.6	9,500	10
1596	Pine	46.4	92.8	9,000	9
1597	Becker	47.1	95.4	8,900	4
1600	Cass	46.8	94.4	9,400	6
1601	Beltrami	47.5	95.0	8,600	5
1602	Itasca	47.8	93.3	8,800	6
WISCONSIN					
1605	Bayfield	46.7	91.0	9,000	13
1606	Forest	46.0	88.9	8,500	12
1608	Burnett[3]	45.9	92.1	10,000	10
1609	Marinette	45.2	88.3	9,600	14
1610	Oneida	45.8	89.8	9,000	10
1611	Wood	44.4	89.7	10,000	13
MICHIGAN (Upper Peninsula)					
1612	Gogebic	46.2	89.2	8,500	12
1613	Ontonagon	46.6	89.0	8,800	15
1614	Alger	46.3	86.7	8,100	15
1615	Chippewa	46.3	84.8	8,000	15
1621	Luce	46.6	85.4	7,900	16
MICHIGAN (Lower Peninsula)					
1616	Manistee	44.2	86.2	10,100	22
1617	Ogemaw	44.2	84.1	9,600	19
1618	Alpena	45.0	83.5	9,000	19

[1]Data from Stoeckeler and Rudolf (1956).

[2]Normal annual sum of average daily temperatures of 50°F or above.

[3]Not planted at University of Minnesota CFC (Plantation 6).

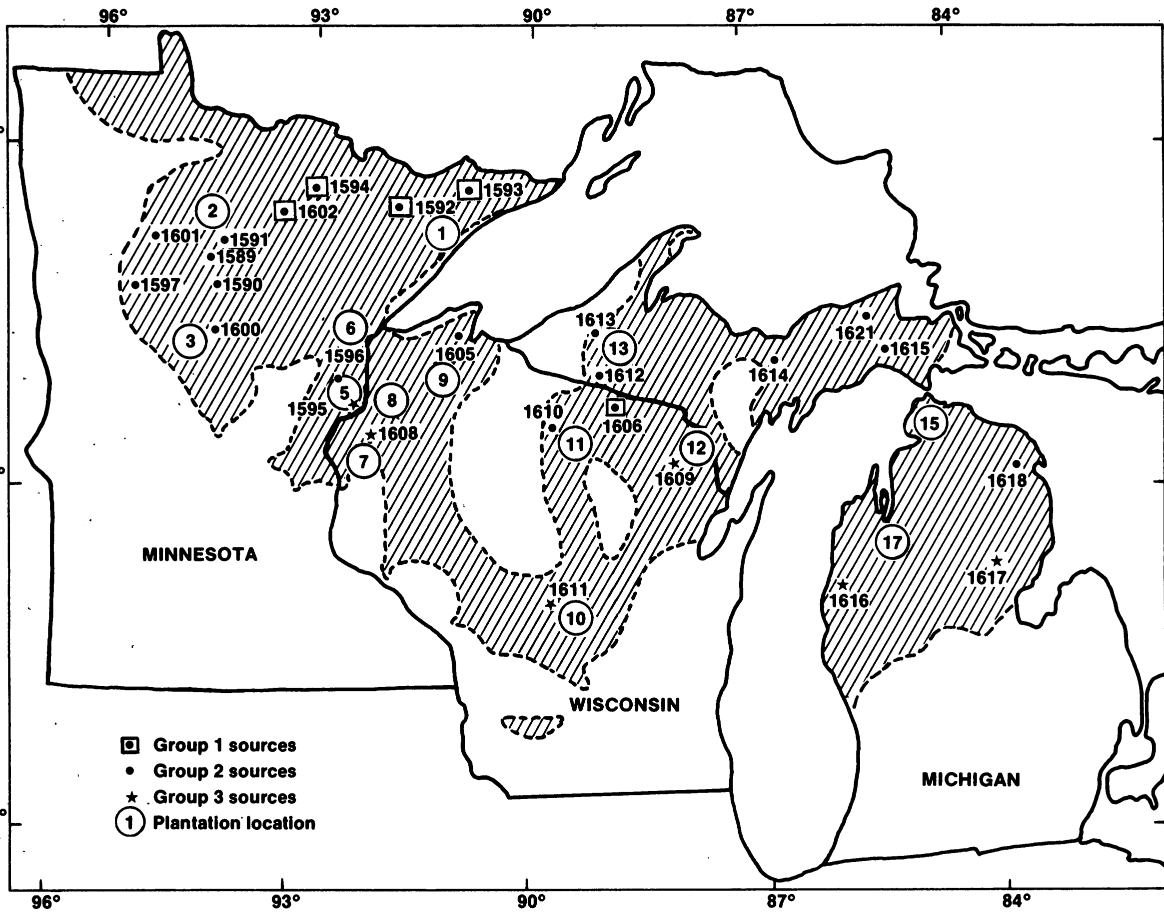

Figure 1.—*Location of seed sources and plantations included in 20-year measurements. Shaded area shows natural range of jack pine (Rudolf and Schoenike 1963).*

decided to measure eight trees per plot. Total height was measured to the nearest 0.5 foot and diameter to the nearest 0.1 inch.

Volume

An equation for estimating volume of a tree from its height and d.b.h. was developed for a subsample of trees, made up of 10 of the 26 sources at each of three plantations: Burnett County Forest (CF), Argonne Experimental Forest (EF), and Ottawa National Forest (NF). A single tree with height and diameter approximating the average height and diameter of the eight measured trees was selected from each of the 10 seed sources in each of the four replications. Sample trees were cut as close to the ground as possible and all limbs removed. The stems were cut into eight equal-length sections and the volume of wood in each section was determined using the volume formula for the frustum of a cone.

By using transformations of the Behre equation of tree form (Bruce 1972), we found that although there appeared to be some slight differences in form among the three plantations, there were no apparent differences in form among sources. Consequently, this prediction equation was used for estimating tree volume for all seed sources at all locations:

$$\text{Vol (cu ft)} = .1781 + .3361\,(\text{d.b.h.})^2\text{ht} - (.01/\text{d.b.h.})$$

Total volume per acre was estimated for each plot by taking (average volume per tree) × (number of trees per acre initially = 1,740) × (proportion survival).

Table 2.—*Location of jack pine plantations*

Number	Forest	County	Plantation establishment	Latitude	Longitude	Growing degree days	Average January temperature
				°N	°W		°F
			MINNESOTA				
1	Superior NF[1]	Lake	USDA For. Serv.	47.6	91.1	7,400	10
2	Chippewa NF	Beltrami	USDA For. Serv.	47.4	94.5	8,600	5
3	Pillsbury SF	Cass	Minn. Cons. Dep.	46.4	94.5	9,400	6
5	General Andrews EF	Pine	Minn. Cons. Dep.	46.4	92.8	8,700	9
6	Univ. Minn. CFC	Carlton	Univ. Minn.	46.7	92.5	8,500	8
			WISCONSIN				
7	Burnett CF	Burnett	Burnett Co.	45.6	92.8	10,000	10
8	Mosinee IF	Washburn	Mosinee Pap. Co.	46.2	92.0	10,000	10
9	Chequamegon NF	Bayfield	USDA For. Serv.	46.3	91.4	9,000	13
10	Nepco IF	Wood	Nekossa-Edwards Pap. Co.	44.2	89.8	10,000	13
11	Argonne EF	Forest	USDA For. Serv.	45.8	89.0	8,500	12
12	Marinette CF	Marinette	Marinette Co.	45.7	88.0	9,600	14
			MICHIGAN (Upper Peninsula)				
13	Ottawa NF	Ontonagon	USDA For. Serv.	46.3	89.2	8,500	12
			MICHIGAN (Lower Peninsula)				
15	Univ. Mich. BS	Emmet	Univ. Mich.	45.5	84.7	8,700	17
17	Fife Lake SF	Grand Traverse	Mich. Cons. Dep.	44.5	85.4	9,700	18

[1]NF: National Forest; SF: State Forest; EF: Experimental Forest; CFC: Cloquet Forestry Center; CF: County Forest; IF: Industrial Forest; BS: Biological Station.

Statistical Procedures

Analyses of variance

Two-way analyses of variance by source and replication were performed for survival, height, diameter, volume per tree, and volume per acre for each plantation. Combined analyses of data from all locations were also run for these variables. Because variances were quite different among plantations, log transformations of the data were used in the combined analyses to bring about homogeneity. Data on volume per acre from plantations at Pillsbury State Forest (SF) in Minnesota and Nepco Industrial Forest (IF) in Wisconsin were not included in the combined analysis because the transformation gave logs of negative values.

From the two-way analysis of variance for each plantation, an estimate of the "true" variation among sources was obtained as a "component of variance" after allowance for random variation (Snedecor and Cochran 1967). The corresponding standard deviations, denoted by $\hat{\sigma}_s$, represent the variability among sources. In tables 3-7, estimated ranges among sources (plantation mean $\pm\ 2\hat{\sigma}_s$), are shown for each plantation. These ranges would include 95 percent of a normal distribution, and approximately 95 percent of a distribution with moderate deviation from normal. It does not appear that the distributions of "true" values for sources differ markedly from normal, so that a value equal to the plantation mean $+\ 2\hat{\sigma}_s$ would represent a source near the top of the distribution, while a value equal to the plantation mean $-\ 2\hat{\sigma}_s$ would represent a source near the bottom. These points are more stable than the maxima and minima of the observed means and were used to assess the potential gain from proper seed source selection for a given location. A few sources will have values outside this range, so this treatment is conservative. In the case of tree survival, values were calculated using the arcsin transformation and then transformed back. The range of variation among sources is much greater for some plantations than for others.

Grouping of sources

Because mean values for a single source at an individual plantation had fairly large standard errors, we tried grouping plantations and also sources. However, grouping of plantations was not very successful, primarily because of large differences among plantations.

We found that sources could be arranged into three broad groups based on simple correlation coefficients among individual sources over the 14 plantations for measurements of height, d.b.h., and volume per tree. The separation was clearest for height, where 83 percent of the correlation coefficients between pairs of sources in the same group were 0.95 or above, as compared with 11 percent for sources not in the same group. For d.b.h., correlations were lower and less consistent. Fifty-two percent of the correlations between pairs of sources in the same group were greater than 0.90, compared with 25 percent for sources in different groups. Results for volume per tree were intermediate, with 82 percent of the correlation coefficients in the same group greater than 0.90 compared with 49 percent for sources in different groups.

A few sources correlated well with both group two and group three sources, and could have been assigned to either group. A few sources that did not fit closely into any group were put into the group having the best agreement.

Correlations

For each plantation, simple correlations were run between (a) average source survival, height, diameter, volume per tree, and volume per acre and (b) growing degree days and latitude of seed origin. Simple correlations among sources were also run between heights at 5 and 10 years, 5 and 20 years, and 10 and 20 years, after planting for each of 13 locations where measurements from the three periods were available.

RESULTS AND DISCUSSION

Survival

Average tree survival 20 years after plantation establishment varied from 53 percent at Pillsbury SF in central Minnesota to 92 percent at Fife Lake SF in Lower Michigan (table 3). Survival at six locations was less than 80 percent. Much of the initial mortality at these locations was attributed to inadequate cultural treatment after planting, and insect and animal damage. Much continuing mortality is attributable to reduced tree vigor resulting from insect and disease incidence (King 1971, King and Nienstaedt 1965). Continuing mortality is most prevalent at locations with high incidence of gall rust. Trees with galls on main stems are particularly susceptible to breakage from high winds, ice, and heavy, wet snows.

Seed sources showed considerable variation in survival at all locations; differences were significant at all locations except the University of Michigan Biological Station (BS). In the combined analysis, differences among plantations and seed source × location interactions were significant.

Five of eight plantations exhibiting high variability among sources in survival had high gall rust incidence. The southernmost plantation, Nepco IF, showed much greater variation than the other plantations. This plantation not only had a high incidence of gall rust (King 1971), but also a high incidence of needlecast (King and Nienstaedt 1965) and root tip weevil (*Hylobius rhizophagus* M.B. & W.). At this location, northern Minnesota sources had very poor survival and high gall rust and needlecast incidence, while sources from the southern portion of the species range had good survival and relatively low rust and needlecast incidence.

At 10 of the 14 locations, the source from nearest the planting site (local) was among the top eight of the 26 sources in survival. At 12 locations survival of the local source exceeded that of the commercial source by 4 to 33 percent. At the remaining two locations, University of Minnesota Cloquet Forestry Center (CFC) and the University of Michigan BS, survival of both local and commercial sources was between 85 and 90 percent and differed by less than 1 percent. Survival of commercial sources was relatively low, compared with other sources, at most locations.

Survival was related to similarity between climate and length of growing season at seed origin and at the plantation location. In the seven plantations having cooler climates and shorter growing seasons (growing degree days of 8,700 or less), best survival was attained by trees from Minnesota

Table 3.—*Survival percent of jack pine seed sources*

MINNESOTA

Seed source	1 Superior NF**[1]	2 Chippewa NF *	3 Pillsbury SF **	5 General Andrews EF **	6 Univ. Minn. CFC *	7 Burnett CF **	8 Mosinee IF **	9 Chequamegon NF **	10 Nepco IF **	11 Argonne EF **	12 Marinette CF **	13 Ottawa NF **	15 Univ. Mich. BS	17 Fife Lake SF **
Mean	82	81	53	85	85	85	79	63	65	68	86	77	90	92
Range[2]	93	87	68	92	90	94	95	77	89	79	93	89	95	96
	67	76	38	78	81	76	61	50	37	55	79	65	86	88
MINNESOTA														
1589	84	83	58	91	87	85	82	67	52	71	91	83	90	95
1590	73	88	60	78	81	88	85	57	59	71	91	78	94	92
1591	88	81	60	88	91	86	82	73	43	65	89	79	86	91
1592	[3]91	79	47	88	89	71	64	46	45	69	79	86	91	93
1593	92	88	52	90	88	70	74	57	34	72	90	88	93	96
1594	89	82	48	83	84	78	62	50	41	70	73	77	89	89
1595	78	80	55	88	90	88	88	71	70	67	86	82	90	91
1596	82	86	68	[3]90	[3]86	89	88	71	74	73	86	74	91	94
1597	77	85	56	85	90	84	81	59	63	67	84	74	89	95
1600	85	87	[3]62	84	86	88	91	68	54	69	88	77	91	93
1601	79	[3]85	61	89	86	89	80	68	60	68	87	70	93	95
1602	81	83	43	88	84	79	59	52	46	77	77	81	85	89
WISCONSIN														
1605	81	81	64	84	84	84	89	[3]72	66	71	85	73	86	89
1606	76	74	27	78	79	81	71	55	59	[3]69	78	75	80	83
1608	82	84	58	84	—	[3]89	[3]90	82	70	66	91	82	93	95
1609	68	82	53	86	75	93	86	63	80	60	[3]86	71	87	91
1610	88	79	39	89	83	88	74	62	86	66	91	67	96	91
1611	76	82	64	73	86	91	94	61	[3]83	48	88	57	92	95
MICHIGAN (Upper Peninsula)														
1612	85	78	32	84	90	84	76	68	67	68	87	[3]85	88	94
1613	84	77	54	86	89	88	76	57	60	68	86	84	88	93
1614	91	85	54	85	84	84	77	71	71	73	80	78	87	90
1615	90	80	55	89	89	88	74	59	75	81	90	82	91	90
1621	87	72	52	91	86	87	70	65	76	75	89	89	96	89
MICHIGAN (Lower Peninsula)														
1616	73	71	45	84	87	89	86	71	89	60	86	70	93	[3]94
1617	65	83	51	73	75	91	85	56	81	53	91	66	86	95
1618	78	75	59	88	84	84	82	67	74	59	86	79	[3]88	91
COMMERCIAL SEED SOURCE														
	87	73	52	76	87	65	71	50	50	64	79	78	89	89

[1]Significant differences among seed sources: * = 5 percent; ** = 1 percent.

[2]Estimated range (plantation mean ± $2\hat{\sigma}_s$).

[3]Seed source nearest planting site (local).

and Upper Michigan. The majority of these trees was from areas having less than 9,000 growing degree days.

Conversely, at the other seven locations (9,000 growing degree days or more) best survival was attained by trees from areas having warmer climates and longer growing seasons than at the planting site. Included in this group were sources 1596 and 1600 from Minnesota, sources 1608, 1609, 1611 from Wisconsin, and sources 1616 and 1617 from Lower Michigan. Predominating among the sources with the poorest survival at these locations were the four northernmost sources—1592, 1593, 1594, and 1602 from Minnesota—and source 1606 from northern Wisconsin. Source 1606, from the coldest site in Wisconsin, was among the sources showing lowest survival at 10 of the 14 locations.

High incidence of gall rust at several of the warmer locations, including the Pillsbury SF, Burnett CF, Mosinee IF, Chequamegon NF, and Nepco IF (King 1971), probably resulted in increased mortality. Furthermore, since seed sources vary in their susceptibility to gall rust, the high incidence at these locations could have caused the increased variation among seed sources in survival. In general, seed sources with the highest rust incidence had the poorest survival.

Height

Average tree height in the plantations ranged from 18.9 feet at the University of Michigan BS in northern Lower Michigan to 33.3 feet at the Pillsbury SF in central Minnesota (table 4). There were significant differences in tree height among sources at all locations except the University of Minnesota CFC; the combined analysis showed that differences among plantations and seed source × location interaction were significant.

The estimated superiority of a source at the top of the distribution (plantation mean + $2\hat{\sigma}_s$) compared with one at the bottom (plantation mean − $2\hat{\sigma}_s$), as a percent of plantation mean, varied from 10 percent at the University of Minnesota CFC to 49 percent at Mosinee IF. In general, variation among sources within plantations increased with the number of growing degree days at the planting site, but variation was not significantly correlated with latitude of plantation or site quality (based on average plantation height). The greatest variation among seed sources in tree height occurred at locations with high incidence of gall rust; sources from northern Minnesota had the slowest growth and highest gall rust incidence, while sources from the southern portion of the species range in Minnesota, Wisconsin, and Michigan had the greatest height growth and lowest rust incidence.

In general, the "best" seed sources were local ones and those within 100 miles south of the planting site. The number of growing degree days for these sources was nearly equal to or greater than the number at the planting site. Trees from the local source exceeded the average plantation tree height by 2 to 19 percent at all locations; the local source was among the seven tallest sources at 13 locations. At 11 locations, the local source exceeded the commercial source by 4 to 13 percent.

Except at the Superior NF, where northeastern Minnesota sources were the best, one or more of the three Lower Michigan sources were among the five tallest sources at all locations. At eight plantations, one of the Lower Michigan sources was the tallest. Other sources producing the tallest trees at several locations were 1595, 1596, 1600, and 1601 from Minnesota, and 1610 from northern Wisconsin.

Six sources produced the shortest trees at several locations: 1592, 1593, 1594, and 1602 from northeast Minnesota (the four northernmost sources), source 1606 from northern Wisconsin, and source 1621 from Upper Michigan. All six of these sources have less then 8,900 growing degree days.

Diameter

Average plantation tree diameter varied from 3.15 inches at the Mosinee IF to 4.75 inches at the Pillsbury SF (table 5). Average tree diameter for a source was significantly and positively correlated with average tree height for the source at each location.

A combined analysis with data from all locations showed significant tree diameter differences among sources and plantations, and a significant seed source × plantation interaction.

Table 4.—*Average height of trees from jack pine seed sources as a percent of the plantation mean*

Seed source	1 Superior NF**[1]	2 Chippewa NF **	3 Pillsbury SF **	5 General Andrews EF **	6 Univ. Minn. CFC	7 Burnett CF **	8 Mosinee IF **	9 Chequamegon NF **	10 Nepco IF **	11 Argonne EF **	12 Marinette CF **	13 Ottawa NF **	15 Univ. Mich. BS**	17 Fife Lake SF **
Mean (ft)	23.3	23.9	33.3	27.5	29.4	25.9	23.5	27.2	23.8	30.1	29.2	29.3	18.9	19.4
Range[2] (ft)	24.8	25.6	37.3	30.0	30.8	27.8	29.3	30.3	28.7	32.0	31.8	31.8	21.0	21.1
	21.8	22.2	27.3	25.0	28.0	21.6	17.7	24.1	18.9	28.2	26.7	26.8	16.7	16.7
MINNESOTA														
1589	103	99	100	109	99	99	106	104	96	99	106	102	103	104
1590	100	102	102	100	99	100	106	99	95	101	102	102	102	102
1591	100	100	103	101	102	98	101	99	98	90	94	98	97	95
1592	[3]104	102	99	97	100	87	71	87	91	100	92	88	98	97
1593	103	95	89	84	95	86	79	95	83	98	93	93	94	93
1594	101	91	89	92	94	79	71	86	81	99	91	92	90	87
1595	92	104	104	109	99	109	116	104	107	94	101	99	100	105
1596	101	105	102	[3]104	[3]105	105	108	103	103	102	98	101	101	102
1597	105	105	104	103	100	103	107	100	98	104	100	100	101	99
1600	99	105	[3]109	103	101	103	113	106	94	102	101	101	99	99
1601	106	[3]107	105	98	102	105	104	103	102	104	101	100	106	102
1602	106	95	90	97	100	89	83	92	89	101	92	100	94	95
WISCONSIN														
1605	94	102	103	95	94	99	101	[3]102	95	101	102	104	98	96
1606	101	93	82	94	88	90	92	96	95	[3]102	100	100	90	96
1608	101	100	107	102	—	[3]110	[3]109	106	109	94	101	101	103	103
1609	96	101	104	101	97	107	111	101	116	100	[3]103	101	101	99
1610	104	105	101	105	106	104	104	104	111	103	104	105	106	105
1611	94	95	104	106	97	107	115	97	[3]113	89	99	91	104	98
MICHIGAN (Upper Peninsula)														
1612	99	104	100	99	106	105	101	104	99	101	100	[3]105	98	100
1613	104	101	102	104	102	96	95	99	90	106	105	103	96	98
1614	97	98	98	97	103	100	98	94	98	98	99	97	92	89
1615	99	97	96	98	100	97	91	98	92	102	98	102	96	97
1621	96	91	94	96	101	93	92	96	95	97	92	97	96	89
MICHIGAN (Lower Peninsula)														
1616	98	99	106	105	102	116	117	109	122	102	107	105	115	[3]119
1617	98	101	100	102	101	114	106	105	118	102	112	104	114	111
1618	99	105	108	99	103	104	106	112	111	106	105	109	[3]108	115
COMMERCIAL SEED SOURCE														
	107	96	104	94	105	97	97	97	102	98	98	101	111	113

[1]Significant differences among seed sources: ** = 1 percent level.

[2]Estimated range (plantation mean ± $2\hat{\sigma}_s$).

[3]Seed source nearest planting site (local).

Table 5.—*Average diameter of trees from jack pine seed sources as a percent of the plantation mean*

Seed source	1 Superior NF	2 Chippewa NF	3 Pillsbury SF **[1]	5 General Andrews EF	6 Univ. Minn. CFC	7 Burnett CF **	8 Mosinee IF **	9 Chequamegon NF *	10 Nepco IF **	11 Argonne EF **	12 Marinette CF *	13 Ottawa NF **	15 Univ. Mich. BS*	17 Fife Lake SF **
Mean (in)	3.77	3.59	4.75	3.65	3.88	3.47	3.15	4.16	3.48	4.46	3.99	4.01	3.27	3.31
Range[2] (in)	3.95	3.83	5.37	3.88	4.03	3.75	3.65	4.56	3.82	4.90	4.30	4.43	3.50	3.62
	3.59	2.98	4.13	3.42	3.73	3.19	2.65	3.76	3.14	4.02	3.68	3.59	3.04	3.00
MINNESOTA														
1589	106	94	92	105	93	98	103	105	100	102	100	103	107	104
1590	104	97	93	101	100	96	100	105	91	93	103	97	100	100
1591	100	98	103	101	98	95	96	92	102	90	95	94	95	91
1592	[3]100	105	108	97	99	93	77	91	96	95	96	82	96	92
1593	99	90	80	85	96	95	88	94	88	97	91	86	102	102
1594	97	92	89	94	92	90	78	83	95	91	96	92	90	88
1595	93	109	109	116	99	106	113	104	103	102	104	100	104	110
1596	99	105	95	[3]99	[3]105	99	102	97	98	93	103	103	105	101
1597	99	101	104	100	95	99	101	103	97	105	100	99	96	103
1600	100	101	[3]110	103	101	97	108	108	92	97	107	102	98	95
1601	105	[3]105	97	101	99	100	104	101	103	104	101	104	106	97
1602	106	92	105	98	106	92	87	96	97	93	98	101	99	99
WISCONSIN														
1605	95	103	96	96	99	101	96	[3]102	99	96	105	106	104	101
1606	101	106	95	97	90	98	104	102	108	[3]105	103	104	91	105
1608	101	98	107	97	—	[3]108	[3]104	95	107	95	96	91	104	102
1609	99	100	98	100	112	105	109	104	103	107	[3]104	99	97	97
1610	100	105	109	99	109	97	99	99	101	104	98	103	102	104
1611	105	104	107	113	101	105	105	100	[3]102	98	98	104	98	98
MICHIGAN (Upper Peninsula)														
1612	100	109	109	99	106	106	105	112	103	105	94	[3]107	102	99
1613	101	96	102	103	99	99	95	94	94	103	105	102	97	99
1614	101	95	90	100	99	101	102	91	101	91	99	92	95	94
1615	93	103	92	103	94	98	99	100	96	102	97	103	98	98
1621	94	95	88	98	103	95	102	99	95	99	86	96	98	96
MICHIGAN (Lower Peninsula)														
1616	98	99	113	100	97	109	110	97	111	113	112	109	109	[3]109
1617	109	96	101	105	109	112	103	116	113	113	111	114	110	105
1618	93	105	107	95	100	101	104	107	105	112	101	106	[3]100	115
COMMERCIAL SEED SOURCE														
	103	94	106	102	111	103	97	107	112	102	102	103	100	107

[1]Significant differences among seed sources: * = 5 percent; ** = 1 percent.

[2]Estimated range (plantation mean ± $2\hat{\sigma}_s$).

[3]Seed source nearest planting site (local).

There was a significant negative correlation between average plantation diameter and survival (r = −0.696). Thus, considering all 14 plantings as a whole, high mortality resulted in reduced competition and, hence, greater growth. The relation among sources within plantations was much more complex. D.b.h.-survival correlations were significant at six locations; they were negative at the University of Minnesota CFC, Argonne EF, and Ottawa NF, but positive at the Burnett CF, Mosinee IF, and Nepco IF.

Seed sources varied significantly in tree diameter at all locations in Michigan and Wisconsin, but at only one location in Minnesota, the Pillsbury SF (table 5). Variation among sources in diameter was significantly and negatively correlated with average plantation survival, but was not correlated with growing degree days, latitude, or site quality of plantation. Variation among sources was greatest at the Pillsbury SF and least at the Superior NF.

The average of the coefficients of variation among sources over all plantations was significantly less for diameter than for height. This substantiates Funk's (1975) conclusion for white pine that height is a better indication of genetic differences than diameter.

Superiority of trees from local sources was not as evident for diameter as for height. Local sources ranked among the top eight of the 26 sources at only eight locations. They did, however, equal or exceed the average tree diameter of all sources at all locations.

In general, trees from the Lower Michigan sources had the greatest average diameter; at least one of these sources was among the best sources at 10 of the locations, and all three Lower Michigan sources were among the top five sources at the Nepco IF and Argonne EF in Wisconsin, and at the Ottawa NF and Fife Lake SF in Michigan. Source 1595 from Pine County, Minnesota, was among the top five sources at three Minnesota and two northwest Wisconsin locations. And source 1612 from western Upper Michigan was among the five best sources at three locations in Minnesota, three in Wisconsin, and at the Upper Michigan location.

Sources 1595 and 1618, which were among the best in diameter growth at several locations, were among the poorest at the Superior NF. And except at the Superior NF, sources 1592, 1593, and 1594 from northeastern Minnesota were among the five poorest sources at 8, 9, and 11 locations, respectively. Also among the five poorest sources at six locations were 1614 and 1621 from Upper Michigan.

Volume

Volume per tree

Average volume per tree ranged from 0.67 cubic feet at the University of Michigan BS to 2.09 cubic feet at the Pillsbury SF (table 6). Sources varied significantly in volume per tree at all locations except the University of Minnesota CFC, and the combined anlysis showed significant differences among plantations and a significant seed source × location interaction.

Frequently, volume per tree may be affected by stand survival. However, in this study correlations between average seed source volume per tree and survival were significant at only four locations. The correlations between these traits were positive at the Burnett CF, Mosinee IF, and Nepco IF, but negative at the Ottawa NF. Because volume per tree is a function of diameter squared, the relations between survival and diameter at these locations also explain the relations between survival and volume per tree.

The estimated superiority of a source at the top of the distribution (plantation mean + $2\hat{\sigma}_s$) compared with one at the bottom (plantation mean − $2\hat{\sigma}_s$), as a percent of the plantation mean, varied from 13 percent at the University of Minnesota CFC to 94 percent at the Burnett CF.

Variation among sources within plantations in volume per tree was greater than the variation among sources in survival, height, and diameter. Variation among sources in this trait was not significantly correlated with growing degree days or latitude at the planting site. Unusually large variation among sources in volume per tree occurred at the Pillsbury SF in Minnesota. Not surprisingly, variation among sources in diameter was also greatest at this location. Variation among sources was relatively high at all locations in Wisconsin and in western Upper Michigan, while relatively low at the remaining four locations in Minnesota and at both locations in Lower Michigan. In general, variation among sources in volume per

Table 6.—*Average volume per tree of trees from jack pine seed sources as a percent of plantation mean*

Seed source	1 Superior NF	2 Chippewa NF *	3 Pillsbury SF **	5 General Andrews EF *	6 Univ. Minn. CFC	7 Burnett CF **	8 Mosinee IF **	9 Chequamegon NF **	10 Nepco IF **	11 Argonne EF **	12 Marinette CF **	13 Ottawa NF **	15 Univ. Mich. BS	17 Fife Lake SF **
Mean (cu. ft)	.99	.94	2.09	1.09	1.28	.95	.75	1.36	.89	1.69	1.34	1.36	.67	.69
Range[2] (cu. ft)	1.10	1.08	2.75	1.29	1.36	1.57	1.05	1.70	1.18	2.04	1.62	1.67	.80	.87
	.88	.80	1.43	.89	1.20	.68	.45	1.02	.60	1.34	1.06	1.05	.54	.51
MINNESOTA														
1589	112	89	85	116	88	95	108	112	97	101	104	105	113	108
1590	107	96	89	101	99	93	102	109	81	90	106	96	101	99
1591	99	98	106	101	100	91	94	85	100	77	87	87	90	83
1592	[3]103	111	113	90	98	79	52	74	86	90	86	65	91	85
1593	101	78	59	65	88	81	68	85	70	92	80	72	97	97
1594	95	79	73	83	81	69	53	64	78	84	85	82	78	73
1595	82	120	120	137	96	117	136	109	110	97	108	100	105	120
1596	101	112	91	[3]103	[3]114	101	108	95	99	88	102	104	107	103
1597	101	104	111	101	92	99	106	107	92	111	99	99	94	102
1600	100	105	[3]127	109	103	98	122	120	82	95	113	104	97	91
1601	115	[3]115	97	100	100	103	108	104	105	111	102	106	115	95
1602	116	82	101	94	110	79	68	87	87	86	90	101	93	93
WISCONSIN														
1605	87	108	95	89	93	98	91	[3]104	93	94	109	113	104	97
1606	103	103	75	88	77	91	99	101	107	[3]110	105	105	79	104
1608	103	96	119	95	—	[3]122	[3]112	95	122	86	93	84	108	105
1609	94	101	97	99	121	115	122	107	116	111	[3]108	99	95	95
1610	104	113	117	103	121	97	99	99	110	108	99	109	106	110
1611	104	101	114	128	98	114	120	95	[3]113	86	95	98	98	95
MICHIGAN (Upper Peninsula)														
1612	99	118	116	96	115	114	108	126	103	111	91	[3]116	101	97
1613	106	94	104	108	101	94	87	89	82	110	114	105	92	96
1614	98	89	81	99	99	101	102	80	99	83	97	83	86	82
1615	87	101	82	101	89	93	90	97	86	104	92	108	93	94
1621	87	83	74	92	104	87	95	93	86	94	71	89	94	86
MICHIGAN (Lower Peninsula)														
1616	94	97	132	103	96	130	129	101	141	125	128	120	128	[3]131
1617	113	92	101	110	116	137	108	136	139	127	131	132	128	117
1618	89	114	121	90	101	104	111	123	120	130	106	118	[3]105	143
COMMERCIAL SEED SOURCE														
	112	88	113	101	125	101	91	108	124	101	100	105	108	124

[1]Significant differences among seed sources: * = 5 percent; ** = 1 percent.

[2]Estimated range (plantation mean ± $2\hat{\sigma}_s$).

[3]Seed source nearest planting site (local).

tree was greater at locations with high gall rust incidence.

The local source exceeded the plantation average by 3 to 31 percent at all locations and the commercial source by 2 to 27 percent at nine locations. Because volume per tree was determined from the diameter squared and height, ranking of sources for volume per tree was similar to that for diameter.

Volume per acre

In terms of productivity, volume per acre is the most important trait we studied. Average volume per acre ranged from 1,041 cubic feet at the University of Michigan BS in Lower Michigan to 2,012 cubic feet at Marinette CF in northeastern Wisconsin (table 7). The best plantations, Pillsbury SF and the University of Minnesota CFC in Minnesota, and Argonne EF and Marinette CF in Wisconsin, produced 1,899 to 2,012 cubic feet of wood per acre. At each of these locations, average height exceeded 29 feet and average diameter was greater than 3.8 inches. The poorest plantations, Mosinee IF and Nepco IF in Wisconsin, and the University of Michigan BS and Fife Lake SF in Michigan, however, produced only 1,041 to 1,112 cubic feet of wood per acre. Average height at these locations was less than 24 feet while average diameter was less than 3.5 inches. In addition to poor site quality, growth at the Mosinee IF and Nepco IF was probably also affected by high incidence of gall rust and/or other pests.

A combined analysis with data from all locations showed significant differences in this trait among sources and plantations, and a significant seed source × location interation.

Except at the University of Michigan BS, correlations between average seed source volume per acre and height were greater than those between volume per acre and diameter.

Differences in volume per acre among seed sources were considerable at all locations, and statistically significant at 11 locations; variation among sources was not significant at the Chippewa NF, University of Minnesota CFC, and Argonne EF (table 7). The least variation among seed sources in volume per acre occurred at the University of Minnesota CFC, while the greatest variation among sources occurred at the Nepco IF. High variability among sources also occurred at the other plantations having high gall rust incidence, including the Pillsbury SF, Burnett CF, Mosinee IF, and Chequamegon NF. The estimated superiority of a source at the top of the distribution (plantation mean + $2\hat{\sigma}_s$) compared with one at the bottom (plantation mean $- 2\hat{\sigma}_s$), as a percent of the plantation mean, was 136 percent at the Nepco IF. Differences of this magnitude indicate that tremendous losses in volume production may occur if the wrong seed sources are used in a planting program.

Local sources yielded the greatest volume per acre at the Superior NF, Chippewa NF, and Pillsbury SF in Minnesota, and at the Ottawa NF in Upper Michigan. Local sources ranked among the 10 best sources at all locations. Local sources exceeded the commercial sources at 11 locations, ranging from 15 percent better at the Fife Lake SF to 51 percent better at the Burnett CF. However, the commercial source produced more wood per acre than the local source at the Superior NF, at the University of Minnesota CFC, and at the University of Michigan BS.

The best seed sources included 1595 and 1600 from Minnesota and 1616, 1617, and 1618 from Lower Michigan. The four northeastern Minnesota sources—1592, 1593, 1594, and 1602—and source 1606 from a cold location in Forest County, Wiscosnin, were the poorest sources overall. However, at the northernmost plantation, Superior NF, sources 1592, 1593 and 1602 were among the best, while sources 1595, 1616 and 1618 were among the worst.

Grouping of Seed Sources

As indicated previously, the sources could be arranged into three broad groups based on simple correlation coefficients among individual sources over the 14 plantations for height, diameter, and volume per tree. Correlations among sources within each group were high whereas correlations among sources in different groups were lower. It turned out that this division of sources coincided with a geographical distribution into a northern group (Group 1 sources), central group (Group 2 sources), and southern group (Group 3 sources) (table 8, fig. 1). They follow in a general way the more detailed seed collection zones developed by Rudolf (1956). The results from this study support the concept of geographic seed zones in jack pine;

Table 7.—*Average volume per acre of trees from jack pine seed sources as a percent of plantation mean*

Seed source	1 Superior NF**[1]	2 Chippewa NF	3 Pillsbury SF **	5 General Andrews EF *	6 Univ. Minn. CFC	7 Burnett CF **	8 Mosinee IF **	9 Chequamegon NF **	10 Nepco IF **	11 Argonne EF **	12 Marinette CF **	13 Ottawa NF **	15 Univ. Mich. BS	17 Fife Lake SF **
Mean (cu. ft)	1408	1330	1899	1616	1900	1420	1061	1493	1045	1968	2012	1814	1041	1112
Range[2] (cu. ft)	1660	1520	2777	1912	[3]1900	1955	1654	2086	1755	2287	2509	2142	1277	1427
	1156	1140	1021	1320	1900	885	468	900	335	1649	1515	1486	805	797
MINNESOTA														
1589	114	91	97	125	91	94	111	119	79	106	110	114	113	111
1590	96	102	100	92	96	94	106	92	73	94	112	97	105	100
1591	106	98	123	105	106	91	95	99	66	72	89	90	86	82
1592	[4]115	106	105	94	102	65	41	55	56	92	79	73	92	86
1593	114	85	59	68	90	68	61	75	38	99	84	83	101	101
1594	104	80	66	80	80	62	41	51	50	87	72	83	78	71
1595	79	119	128	142	102	120	149	120	118	98	108	108	105	119
1596	101	118	111	[4]107	[4]115	105	117	108	113	96	101	101	109	105
1597	95	109	117	100	97	97	106	95	88	111	97	97	94	106
1600	104	113	[4]148	107	100	101	138	129	66	97	115	103	99	92
1601	111	[4]120	113	105	101	106	106	113	93	111	103	97	120	98
1602	115	84	79	97	109	73	50	71	63	100	83	109	88	90
WISCONSIN														
1605	86	108	111	88	92	96	100	[4]118	95	102	108	108	100	93
1606	96	94	38	80	73	86	88	81	93	[4]112	95	103	70	93
1608	103	100	132	93	—	[4]126	[4]125	123	130	86	98	90	112	107
1609	78	102	98	100	105	125	129	106	140	98	[4]108	89	91	93
1610	112	110	87	108	117	100	90	98	139	105	105	93	114	108
1611	97	102	139	109	99	121	139	92	[4]140	63	98	71	101	98
MICHIGAN (Upper Peninsula)														
1612	103	115	67	94	122	111	102	135	102	112	91	[4]129	99	98
1613	110	90	105	110	105	96	82	80	75	110	115	114	90	97
1614	111	94	81	99	98	99	95	87	107	91	91	86	83	80
1615	96	99	84	106	93	94	82	90	95	126	95	115	95	92
1621	93	74	72	99	106	87	83	96	97	105	74	104	101	82
MICHIGAN (Lower Peninsula)														
1616	84	86	111	103	98	135	137	113	187	113	127	110	132	[4]134
1617	90	93	94	95	104	145	113	121	168	100	137	113	122	121
1618	85	106	135	94	100	101	112	132	128	114	106	121	[4]103	141
COMMERCIAL SEED SOURCE														
	119	79	110	91	129	75	79	87	94	94	92	107	107	119

[1]Significant differences among seed sources: * = 5 percent; ** = 1 percent.

[2]Estimated range (plantation mean ± $2\hat{\sigma}_s$).

[3]Estimate of $\hat{\sigma}_s$ is 0 in this case.

[4]Seed source nearest planting site (local).

Table 8.—*Growing degree days and January temperature of seed sources within groups*

Group 1			Group 2			Group 3		
Seed source	Growing degree days	January temp.	Seed source	Growing degree days	January temp.	Seed source	Growing degree days	January temp.
		°F			°F			°F
1592	7,400	10	1589	9,200	5	1595	9,500	10
1593	6,700	14	1590	9,400	7	1608	10,000	10
1594	8,500	5	1591	9,100	5	1609	9,600	14
1602	8,800	6	1596	9,000	9	1611	10,000	13
1606	8,500	12	1597	8,900	4	1616	10,100	22
Average	7,980	9.4	1600	9,400	6	1617	9,600	19
			1601	8,600	5	Average	9,800	14.7
			1605	9,000	13			
			1610	9,000	10			
			1612	8,500	12			
			1613	8,800	15			
			1614	8,100	15			
			1615	8,000	15			
			1618	9,000	19			
			1621	7,900	16			
			Average	8,790	10.4			

based on our data, however, the large number of subdivisions proposed by Rudolf appears to be unwarranted for jack pine.

Group 1 corresponds to Rudolf's collection zones 5 and 6. This group includes the four northeastern Minnesota sources, 1592, 1593, 1594, and 1602, and source 1606 from Forest County, Wisconsin. Although source 1606 does not belong to this group geographically, it does belong to it climatically. Forest County, Wisconsin, is poorly covered by weather stations and many sites in the area are colder than the weather records indicate. Therefore, this seed source is probably characterized by a climate with fewer growing degree days than shown in table 1. Group 1 sources represent the most severe climate, with an average of 7,980 growing degree days and an average January temperature of 9.4°F.

Group 3 corresponds to Rudolf's milder zones 2 and 3. Sources in this group include 1595, 1608, 1609, 1611, 1616, and 1617. These are the sources from the southern portion (mildest climate) of the species range in Minnesota, Wisconsin, and Michigan. Sources 1600, 1610, and 1618 and possibly others appear to be borderline between Groups 2 and 3. Group 3 sources have an average of 9,800 growing degree days and an average January temperature of 14.7°F.

Group 2, which includes the remaining 15 sources, corresponds to Rudolf's broad seed collection zone 4. Group 2 sources have an average of 8,790 growing degree days and an average January temperature of 10.4°F. Variation among Group 2 sources in these climatic variables is considerable.

It is obvious that genetic variation in Lake States jack pine is continuous, expressing adaptation to climatic and other environmental factors. In some cases, the species shows adaptation to local conditions—source 1606, for example. Grouping of sources was done to bring out broad patterns of genetic variation.

Table 9 enables comparison of seed source group means for height, diameter, volume per tree, and volume per acre. In each section, column 1 gives the mean value for Group 1; columns 2 and 3 show the ratios of the other two group means to the

Table 9.—*Comparison of seed source groups for height, diameter, and volume*

	Plantation[1]	Height (Group) 1	2	3	Diameter (Group) 1	2	3	Volume/tree (Group) 1	2	3	Volume/acre (Group) 1	2	3
		Ft.	*Percent of group 1*		*In.*	*Percent of group 1*		*$Ft.^3$*	*Percent of group 1*		*$Ft.^3$*	*Percent of group 1*	
1	Superior NF	[2]24.0	98	94	3.80	99	100	1.029	96	95	[2]1532	93	81
11	Argonne EF	30.1	101	97	4.29	104	109	1.565	109	114	1931	105	95
2	Chippewa NF	[2]22.7	107	105	3.48	104	104	.854	113	112	1193	115	112
6	Univ. Minn. CFC	[2]28.0	107	105	3.75	103	106	1.166	112	115	1723	113	111
13	Ottawa NF	[2]27.7	108	106	[2]3.74	108	110	[2]1.160	121	124	1635	116	107
17	Fife Lake SF	[2]18.2	106	113	3.22	102	107	.629	109	122	[2]982	112	127
12	Marinette CF	[2]27.4	107	111	3.86	103	108	[2]1.197	112	124	[2]1662	122	136
15	Univ. Mich. BS	[2]17.6	107	114	[2]3.12	105	108	[2].584	114	126	[2]891	118	129
5	General Andrews EF	[2]25.5	109	113	[2]3.43	106	112	[2].919	120	133	[2]1355	122	127
9	Chequamegon NF	[2]24.8	111	114	[2]3.88	108	110	[2]1.122	125	131	[2]995	159	169
3	Pillsbury SF	[2]29.9	113	116	4.53	104	111	[2]1.757	119	135	[2]1320	149	168
7	Burnett CF	[2]22.3	117	128	[2]3.25	106	115	[2].758	122	153	[2]1006	139	182
10	Nepco IF	[2]20.8	113	131	[2]3.38	101	109	[2].760	112	145	[2]628	157	245
8	Mosinee IF	[2]18.6	129	142	[2]2.74	116	123	[2].512	150	179	[2]595	182	236
	Average	24.1	26.3	27.1	3.60	3.78	3.94	1.001	1.156	1.266	1246	1538	1653

[1]Plantations arranged according to magnitude of differences between group means for height and volume per acre.

[2]At least one significant difference exists among groups at 5 percent level.

mean for Group 1 × 100 percent. The least variation among groups occurred at planting sites with fewer than 8,700 growing degree days, and the greatest variation occurred at sites with 9,000 or more growing degree days. Plantings with the greatest variation also had high incidences of gall rust. The sources in Group 1 had the highest rust incidence, while sources 1595, 1608, and 1611 from Group 3 had the lowest rust incidence (King 1971). Genetic variation in susceptibility to rust probably accentuated the differences among groups at locations with high rust incidence, such as the Burnett CF, Mosinee IF, Chequamegon NF, and Nepco IF.

Growing Season and Daylength at Seed Origin

To determine the relation between growing season or daylength at seed origin and performance variables, simple correlations were run for each plantation between (a) growing degree days and daylength (latitude) at seed origin and (b) survival, height, diameter, volume per tree, and volume per acre (table 10). Survival at the Superior NF, General Andrews EF, Argonne EF, and Ottawa NF—four of the coldest locations—was significantly and negatively correlated with growing degree days, and positively correlated with latitude at seed origin. At the Burnett CF, Mosinee EF, and Nepco IF—three of the warmest locations—survival was significantly and positively correlated with growing degree days and negatively correlated with latitude at seed origin.

Height at the Superior NF, Chippewa NF, University of Minnesota CFC, and Argonne EF was not significantly correlated with growing degree days at seed origin. Correlations between these variables at all other locations, however, were significant, with coefficients ranging from 0.44 at the Ottawa NF to 0.80 at the Mosinee IF.

Correlations between height and latitude at seed origin shifted from a significant positive correlation (r = 0.54) at the northernmost plantation (Superior NF), through nonsignificant correlations, to increasing negative correlations with decreasing latitude of plantation. These results show that the effect of latitude at seed origin on height varies with latitude at the planting site (fig. 2). Graphs showing equally dramatic shifts could also have been drawn for survival and volume per acre.

At the northernmost plantations, no significant correlations were found between seed source diameter and growing degree days or latitude at seed

Table 10.—*Simple correlation coefficients between variables and (a) degree days or (b) latitude at seed origin*

	Plantation[1]	Growing degree days	Lat.	Survival: Degree days	Survival: Lat.	Height: Degree days	Height: Lat.	Diameter: Degree days	Diameter: Lat.	Vol./tree: Degree days	Vol./tree: Lat.	Vol./acre: Degree days	Vol./acre: Lat.
			°N										
1	Superior NF	7,400	47.6	[2]−0.69	0.63		0.54					−0.47	0.64
2	Chippewa NF	8,600	47.4		.40								
6	Univ. Minn. CFC	8,500	46.7		.41								
3	Pillsbury SF	9,400	46.4			.58		.58	−.43	.62	−.45	.60	
5	General Andrews EF	8,700	46.4	−.45	.50	.75	−.45	.59	−.44	.64	−.42	.44	
9	Chequamegon NF	9,000	46.3	.44		.60	−.58		−.47	.45	−.52	.54	−.49
13	Ottawa NF	8,500	46.3	−.60	.57	.44	−.44	.54	−.61	.52	−.61		
8	Mosinee IF	10,000	46.2	.69	−.54	.80	−.65	.60	−.66	.71	−.68	.76	−.66
11	Argonne EF	8,500	45.8	−.60	.71				−.66		−.56		
12	Marinette CF	9,600	45.7			.60	−.67	.62	−.50	.64	−.59	.66	−.62
7	Burnett CF	10,000	45.6	.76	−.63	.73	−.77	.61	−.82	.68	−.83	.75	−.84
15	Univ. Mich. BS	8,700	45.5			.60	−.63			.49	−.50	.41	−.42
17	Fife Lake SF	9,700	44.5			.58	−.64		−.56	.44	−.63	.45	−.60
10	Nepco IF	10,000	44.2	.52	−.87	.71	−.88	.55	−.71	.66	−.84	.64	−.93

[1]Plantations are arranged from north to south.

[2]Only correlations significant at the 5 and 1 percent levels are given (Significance levels r = 0.39—5 percent, r = 0.50—1 percent).

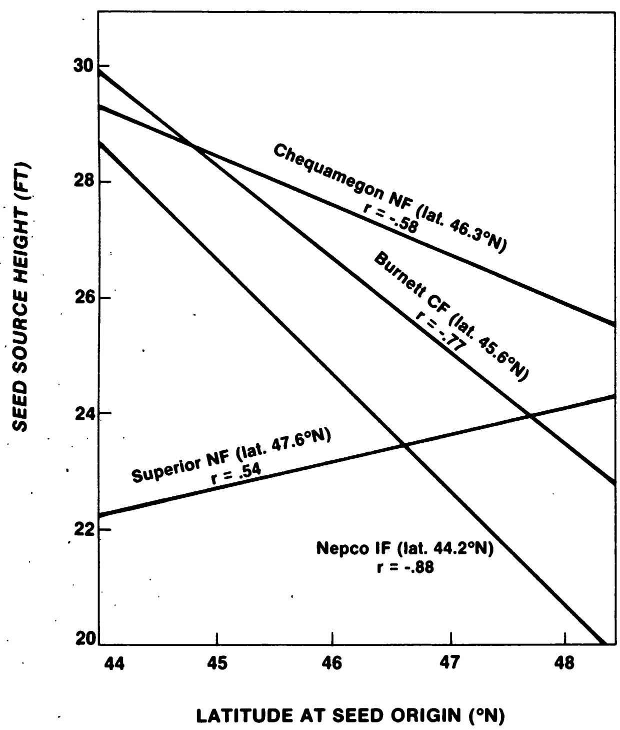

Figure 2.—*Linear regression: average height on latitude at seed source origin.*

origin. At seven of the remaining locations, the correlations between diameter and growing degree days at seed origin varied from 0.54 to 0.62, while the correlations between diameter and latitude tended to increase negatively with decreasing latitude of plantation.

As one might expect, the correlations between volume per tree and growing degree days or latitude were very similar to those between diameter and the latter variables. The correlations between volume per acre and growing degree days or latitude at seed origin were similar to those between height and growing degree days or latitude at seed origin. Only at the Superior NF was the correlation coefficient significant and negative (r = −0.47) for growing degree days at seed origin; at nine of the remaining locations the correlations between volume per acre and growing degree days at seed origin were significant and positive.

Latitude of seed source appeared to influence growth more than growing degree days at seed origin in the northernmost and southernmost plantations, while growing degree days at seed origin appeared to influence growth more than latitude of seed source in middle latitude plantings. The data for height, diameter growth, and volume production of trees from 26 seed sources 20 years after planting add further support to the findings of Morgenstern and Teich (1969) for phenotypic stability of height growth (based on height growth of 16 of the same sources 10 years after planting). Their results and ours show that sources from northeastern Minnesota (Group 1 sources) and from the southern portion of the jack pine range in Minnesota, Wisconsin, and Michigan (Group 3 sources) contribute most to the genotype × environment interactions while those from middle latitudes (Group 2 sources) contribute little to the interactions. Morgenstern and Teich suggested that an apparent reason for these differences is the distance from origin of seed to the planting site (this distance being the least for middle latitude seed sources).

Comparison of Height Growth at 5, 10, and 20 Years

Coefficents of determination ($r^2 \times 100$) between 5-, 10-, and 20-year mean heights among sources at 13 locations are included in table 11. At nine locations, 67 to 92 percent of the variation in height at 20 years was accounted for by height at 10 years. The highest coefficients of determination between 10 and 20 years were found for locations with milder climates. At the coldest locations—Superior NF, Chippewa NF, University of Minnesota CFC, and Argonne EF—less than 60 percent of the variation in height at 20 years could be accounted for by height at 10 years.

Our results indicate that height at age 5 is not a reliable estimate of height at age 20. Less than 67 percent of the variation in height at age 20 could be accounted for by variation in height at age 5.

The coefficients of determination for height at 10 and 20 years for nine locations in the Lake States are similar to or exceed the coefficients of determination for Ontario jack pine heights measured at 11 and 19 years at the Petawawa Forest Experiment Station in Ontario (Yeatman 1974). Therefore, by the time regional jack pine tests are 10 to 15 years old, they can in most cases be used to develop reliable seed source recommendations. Exceptions are tests on the coldest sites, where final differentiation of response may be delayed.

Table 11.—*Coefficients of determination ($r^2 \times 100$) between 5-, 10-, and 20-year mean heights among sources*
(In percent)

	Plantation	5 and 10 years	5 and 20 years	10 and 20 years
1	Superior NF	58	14	41
2	Chippewa NF	35	5	38
3	Pillsbury SF[1]	86	46	74
5	General Andrews EF[2]	56	48	72
6	Univ. Minn. CFC	64	22	58
7	Burnett CF	76	52	81
8	Mosinee IF	49	40	92
9	Chequamegon NF	42	38	86
10	Nepco IF	66	56	76
11	Argonne EF	72	25	49
12	Marinette CF	79	66	83
13	Ottawa NF	55	28	67
17	Fife Lake SF	77	61	90

[1]Heights measured at 5, 11, and 20 years.
[2]Heights measured at 5, 13, and 20 years.

SEED COLLECTION RECOMMENDATIONS

In general, the study results 20 years after planting support the seed collection recommendations made by King (1966) based on results 10 years after planting. If jack pine is to be planted in the Lake States for relatively short rotation pulpwood production (30 to 40 years), the results of this test can be used with confidence.

In any planting program, environmental conditions such as climate, photoperiod, soils, nursery treatment, planting techniques, and damage from insects and diseases interact with the genetic makeup of the plant material and may drastically alter results. To realize the greatest yields in jack pine we must minimize these interactions and we must use the best genetic material for the locale and the best techniques available for raising planting stock and establishing and managing plantations. The first step is careful seed source selection based on the best available information.

Where local seed sources appear to be superior, as in the Minnesota plantations, we recommend using seed from selected stands near the planting site. However, where superiority of nonlocal sources is indicated, as in the Wisconsin plantings, we recommend a cautious approach. In these instances the forest manager might consider mixing seed from selected local stands with seed from the recommended nonlocal seed sources, to insure against possible failure of nonlocal material at later ages.

It is obvious from this study that using the "wrong" seed source will result in considerable volume losses. Using the "right" seed source, however, can result in modest to substantial gains in volume production.

The following recommendations should be followed for planting jack pine in the Lake States:

1. Collect seed from young to middle-aged stands having uniform, normal stocking on good sites.
2. Collect seed from individual trees with good growth and form and little or no evidence of serious pest incidence.
3. In Minnesota use seed collected from selected stands near the planting site.
4. In Wisconsin, at locations having less than 9,100 growing degree days, use seed from selected stands near the planting site and mix with seed from selected proven stands in Upper and Lower Michigan. At warmer locations use seed collected from the southern portion of the species range in Lower Michigan.
5. In Upper Michigan use seed from selected stands near the planting site. In Lower Michigan use seed from the southern portion of the species range in Lower Michigan.

SEED PRODUCTION AREAS

The results of this study can be used to develop jack pine breeding populations for the Lake States. Seed source groups 1, 2, and 3 define effective breeding zones within which we can identify the best stands and best trees on which to base programs for genetic improvement.

The best stands in each breeding zone should be relocated and converted into seed production areas (SPA's). If the original stands are no longer in existence, it may be necessary to use other good jack pine stands in the immediate vicinity. King (1973) recommended that the best stands should be thinned to about 60 trees per acre on the basis of spacing, growth rate, and form. Commercial quantities of seed of better quality than those presently available should be available from these stands within 5 years. When seedlings from these seed collections are available, trees in the SPA's can be harvested and the sites replanted with seedlings originated from the same SPA's. By following this procedure, the genetic integrity of the selected stands will be maintained.

The following stands are recommended for conversion to SPA's:

Zone 1 (Rudolf's (1954) collection zones 5 and 6)

- 1592 Lake County, Minnesota
- 1602 Itasca County, Minnesota

Zone 2 (Rudolf's zone 4)

- 1600 Cass County, Minnesota
- 1610 Oneida County, Wisconsin
- 1612 Gogebic County, Michigan
- 1618 Alpena County, Michigan

Zone 3 (Rudolf's zones 2 and 3)

- 1595 Pine County, Minnesota
- 1596 Pine County, Minnesota
- 1608 Burnett County, Wisconsin
- 1609 Marinette County, Wisconsin
- 1611 Wood County, Wisconsin
- 1616 Manistee County, Michigan
- 1617 Ogemaw County, Michigan

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Variation among Lake States jack pine seed sources in survival, total height, diameter, volume per tree, and volume per acre grown for 20 years at 14 locations in the Lake States are presented and discussed. Seed collection and seed production area recommendations are included.

OXFORD: 232.12:174.7 *Pinus banksiana* (77). KEY WORDS: seed source recommendations, genotype-environment interaction, juvenile-mature correlations, breeding zones.

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