PERFORMANCE OF BLACK WALNUT PROVENANCES AFTER 15 YEARS IN 7 MIDWESTERN PLANTATIONS

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Abstract.--Average 15-year tree height of 15 to 25 black walnut provenances per plantation ranged from 11.8 m in Kansas to 3.6 m in Minnesota. Corresponding d.b.h. values ranged from 22.5 cm to 5.6 cm. Provenances differed significantly within plantations in height, d.b.h., and survival except in the Kansas plantation and in height and d.b.h. in the Missouri plantation. Southern provenances that previously grew well in the Iowa and Minnesota plantations now show low survival, dieback, and growth stagnation. Earlier recommendations that it is safe and advantageous to move provenances as much as 200 miles northward appear to still be valid for plantations in Illinois, Missouri, Ohio, and Michigan on the basis of the current results. Mostly western provenances should be used in Iowa, and Indiana trees should not be used in Kansas. Local trees and provenances from Iowa and northern Illinois are recommended for Minnesota.

Additional keywords: Juglans nigra, survival, growth, age-age correlations, growth trends.

Black walnut (Juglans nigra L.), the premier source of fine cabinet and furniture wood, is planted throughout its natural range and is an excellent candidate for genetic improvement. Successful planting and genetic gains depend, as with other species, partially on locating planting stock that is both hardy and fast growing or, in other words, identifying appropriate provenances. Based on early results of this study, Bey (1973, 1980) showed that trees of southern origin had up to 20 percent greater growth than those of northern origin and concluded that provenances could be moved as much as 200 miles northward without much risk of cold damage. These conclusions are confirmed by this study's 15-year data which also lead to more specific recommendations for plantations in the northwestern part of the species range.

METHODS

In 1967; 1-0 seedlings from 15 to 25 black walnut provenances were planted in each of eight Midwestern states. The Indiana plantation was recently lost due to flooding; therefore, most of the results in this paper are from the remaining seven locations (table 1). Each provenance contained seed from an average of six unselected trees per stand. Trees from most provenances were planted in two or more plantations, but no two plantations had the same set of provenances in common. Each plantation was established in a randomized complete block design with 6 replications and 4-tree row plots. Weeds were controlled by herbicide spraying in all plantations for the first 3 years.

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Table 1.--Location of plantations, number and average survival of black walnut provenances after 15 years in the field

Plantation location			Prove-	Survival of provenances		
State	Lat.	Long.	nances	All	Local[a/]	Tallest[b/]
	°N	°W	No.	- - - -	Percent	- - - - -
Illinois	37.3	89.3	20	83	81	92
Missouri	37.8	92.2	15	85	83	74
Kansas	39.2	96.5	15	52	39	45
Ohio	40.8	81.9	25	67	48	85
Iowa	41.8	91.7	25	69	82	88
Michigan	42.3	85.4	20	81	77	84
Minnesota	44.2	92.0	20	34	66	30
Average				67	68	71

a/Local provenances include those within 100 miles north or south of the plantation latitude.
b/ Tallest20 percent of the provenances.

In the winter of 1981-82, data were collected on survival, height, and d.b.h. of all trees. The Kansas plantation was thinned in 1977; survival in this plantation was, therefore, recorded as:

$$\left(\frac{\text{Number of live trees}}{(\text{Number of planted trees}) - (\text{Number of cut trees})}\right) \times 100$$

Differences in traits among provenances were tested by analysis of variance after arcsine transformation of survival percentages. The relation of tree height in each plantation to geographic origins was tested by stepwise multiple regressions using latitude, latitude^2, latitude^3, longitude, longitude^2, longitude^3, latitude/longitude, and latitude x longitude as independent variables. Correlations of height and d.b.h. after 5, 10, and 15 years in the field were calculated for each plantation and age-age correlations were computed for height and d.b.h. in each plantation using all available measurement data. All analyses were based on plot means.

RESULTS AND DISCUSSION

Survival

Average survival after 15 years ranged from 34 percent in Minnesota to 85 percent in Missouri and differed significantly among provenances in all but the Kansas plantation (table 1). Local provenances--those within 100 miles north or south of the plantation latitude--had below-average survival in Kansas and Ohio but above-average survival in Iowa and Minnesota. Trees from the tallest 20 percent of the provenances were the best survivors in Illinois, Ohio, Iowa, and Michigan, but had below-average survival in Missouri and Minnesota and below-average but better survival than the local provenances in Kansas (table 1). The amount of variation in survival accounted for by the provenance component ranged from 10 percent in Kansas to 63 percent in Minnesota.

Survival showed little linear relation to seed origin except in Minnesota where it was correlated with origin latitude (r = 0.742). In this plantation, survival of trees originating more than 200 miles south of the planting site averaged only 22 percent compared with 79 percent for the local provenance. Those from 300 or more miles south averaged only 12 percent survival and two southern provenances had no survivors. Although the response in the Iowa plantation was not as pronounced, the pattern was similar: trees originating 200 or more miles south of the planting site averaged 61 percent survival compared with 83 percent for the local trees.

Height and Diameter Growth

Average 15-year height ranged from 3.6 m in Minnesota to 11.8 m in Kansas (table 2). Trees from local provenances showed average height growth in 5 plantations but exceeded the plantation mean by 20 percent in Iowa and by 17 percent in Minnesota. Trees from the tallest 20 percent of the provenances ranged from 8 to 36 percent taller and averaged 15 percent taller than the plantation means (table 2). The tallest 20 percent had better height growth than the local provenances in all plantations; the superiority ranged from 3 percent in Kansas to 36 percent in Minnesota.

Table 2.--Average 15-year height and diameter of 15 to 25 black walnut provenances in seven plantations

Plantation	Height of provenances			DBH of provenances		
	All	Local[a/]	Tallest[b/]	All	Local[a/]	Tallest[b/]
	m	- Percent of mean -		cm	- Percent of mean -	
Illinois	5.6	98	123	8.7	99	128
Missouri	5.7	102	110	8.9	101	115
Kansas	11.8	105	108	22.5	108	108
Ohio	9.1	103	108	13.5	99	105
Iowa	5.0	120	128	9.0	121	129
Michigan	6.9	101	113	9.2	102	114
Minnesota	3.6	117	136	5.6	118	145
Average	6.8	106	115	11.0	106	117

a/ Localprovenances include those within 100 miles north or south ofthe plantation latitude.

b/ Tallest 20 percent of the provenances.

Height differences among provenances were significant in all but the Kansas and Missouri plantations and the provenance component accounted for up to 52 percent of the variation in height in the Iowa plantation. Block differences were significant in 5 plantations but contributed little to the height variation--a maximum of 11 percent in the Ohio plantation. Plot variation, however, was large in most plantations with the error component contributing from 39 percent of the variation in height in Missouri up to 95 percent in Kansas.

Stem diameter showed the same pattern as tree height did; the Minnesota plantation had the smallest d.b.h. and the Kansas plantation had the largest (table 2). Local provenances on the average had 6 percent greater d.b.h. than the respective plantation means except in Iowa where their diameters were up to 21 percent larger. The tallest 20 percent of the provenances had from 5 to 45 percent greater d.b.h. than the average for each plantation. Except for the Kansas plantation where their d.b.h. was only equal to that of the local provenances, the tallest 20 percent always had diameters greater than those of the local group; the superiority ranged from 6 percent in Ohio to 45 percent in Minnesota.

As was the case for height, diameter differences were significant in all plantations except Kansas and Missouri and the provenances accounted for up to 51 percent of the variation in d.b.h. in the Iowa plantation. Block differences were only significant in Minnesota where they contributed 10 percent to total d.b.h. variation. Plot variation was again large, ranging from 45 percent in Missouri to 98 percent in Kansas.

Relation of Traits to Origins

The regression analysis showed that 15-year tree height was not related to seed origin latitude in the Missouri, Kansas, and Michigan plantations. In the Illinois plantation, however, southern trees were taller than northern trees as they were at age 10 (Bey 1979) and latitude accounted for 21 percent of the variation in height. In agreement with the 10-year results (Bey 1979), the trend was in the opposite direction in the Ohio, Iowa, and Minnesota plantations where latitude accounted for, respectively, 12, 25, and 12 percent of the height variation. Longitude of seed origin had little or no effect on height except in Kansas and Michigan where it accounted for 7 and 14 percent, respectively, of the variation in height. The stepwise regressions showed that adding from one to seven other variables to the model was not much better than using the single variables latitude or longitude. The improvement in fit by using multiple regressions instead of simple regressions ranged from 2 percent in the Michigan plantation to 21 percent in the Kansas plantation.

Correlations Among Traits

Correlations for height and diameter after 5 and 10 years in the field (Bey 1979) were based on provenance means and, except for those for the Ohio plantation, were higher than those presented in this paper, which are based on plot means. Therefore, 5- and 10-year data for the Indiana plantation are included in table 3 to allow comparison with the other 7 plantations.

Most correlations among heights and diameters after 5, 10, and 15 years in the field were significant. However, 5-year height was poorly correlated with 15-year height and diameter in the Kansas and Minnesota plantations. Similarly, 5-year diameter was poorly correlated with 15-year height and diameter in Kansas and Missouri and with 15-year height in the Minnesota plantation (table 3). Some of the low correlations may be due to the 1977 thinning in the Kansas plantation and to the poor survival in the Minnesota plantation, which led to fewer remaining trees in both locations. The dieback in the Missouri plantation due to the severe winter of 1976-77 reported by Bey (1979) may explain the low correlations in that plantation. In general, 5-year height was more closely related to 10-year height than to 15-year height, and

Table 3.--Average correlations between height and diameter after 5, 10, and 15 years in 8 plantations

Trait and year	Trait and year: Height 10	Height 15	Diameter 5	Diameter 10	Diameter 15	Trait and year: Height 10	Height 15	Diameter 5	Diameter 10	Diameter 15
	Illinois					Indiana				
Height - 5	.54	.49	.46	.53	.42	.76	-[a]	.92	.75	-
- 10		.92	.75	.94	.82		-	.70	.86	-
- 15			.75	.93	.87			-	-	-
Dbh - 5				.74	.61				.78	-
- 10					.88					-
	Missouri					Kansas				
Height - 5	.69	.42	.67	.72	.53	.38	.21	.77	.60	.16
- 10		.74	.45	.88	.70		.48	.44	.55	.40
- 15			.14	.69	.88			.04	.36	.60
Dbh - 5				.44	.22				.61	.16
- 10					.79					.39
	Ohio					Michigan				
Height - 5	.76	.58	.91	.74	.39	.77	.60	.91	.71	.57
- 10		.81	.80	.90	.59		.77	.73	.84	.68
- 15			.61	.77	.78			.59	.76	.86
Dbh - 5				.82	.40				.71	.57
- 10					.70					.80
	Iowa					Minnesota				
Height - 5	.70	.55	.87	.73	.55	.64	.23	.82	-	.28
- 10		.76	.69	.93	.70		.69	.62	-	.68
- 15			.60	.76	.87			.38	-	.94
Dbh - 5				.75	.62				-	.33
- 10					.75					-

[a]- = data not available.

15-year height was more closely related to 10-year height than to 5-year height. Diameter correlations usually followed the same pattern. As expected, correlations between height and d.b.h. at age 15 were high.

Age-age Correlations

Measurements taken at other intervals were added to the 5-, 10-, and 15-year data, and all possible age-age correlations were calculated for height and d.b.h. in each of the 8 plantations. Because heights of black walnut at ages 1 and 2 from seed were previously found to be unreliable predictors of height at later ages (Clausen 1982), 1-year heights were not used in the

calculations. Diameters at 3 years of age proved to be similarly unreliable and were also excluded. Although the age-age correlations varied among the plantations (table 3), the average correlation between height at early ages and height at later ages tended to decrease gradually with increasing tree age (table 4) as found in previous work with young black walnut families (Clausen 1982). The correlation between height at age 16 from seed and earlier ages increased gradually as the time between measurements decreased, which also agrees with the previous findings. The age-age correlation matrix for d.b.h. was not as complete as that for height but generally followed the same pattern.

Table 4.--Average correlations for height of provenances in 8 plantations measured at various ages

Age (years)	Age (years)									
	4	5	6	7	8	9	10	11	13	16
3	.801	.710	.478	.630	.615	.610	-[a/]	.445	.474	.363
4		.830	.775	-	.685	.564	-	.615	-	.326
5			.848	.825	.815	.718	.672	.656	.584	.454
6				.725	.705	.690	.700	.651	.685	.355
7					.886	.880	-	.830	.780	.695
8						.888	-	.885	-	.844
9							.872	.920	.856	.780
10								-	-	.758
11									.911	.735
13										.823

[a/] - = data not available.

An earlier study showed that age-age correlations in black walnut can be estimated by a single regression equation that employs the $\log_e$ of the age ratio (LAR) of any two ages used in an age-age correlation (Clausen 1982). This method was applied to the present data and, as shown below, the results were very similar to those obtained previously:

Study and Trait	Regression Equation	r^2
Provenance test-height	$\hat{r}_{age,age} = 0.914 + 0.350$ (LAR)	0.755
Provenance test-d.b.h.	$\hat{r}_{age,age} = 0.910 + 0.336$ (LAR)	0.797
Progeny test-height	$\hat{r}_{age,age} = 0.975 + 0.387$ (LAR)	0.853

The linear fit of the two provenance regressions is not as close as that of the progeny regression, probably due to the greater diversity of material included in the provenance test, but these regressions, when tested for equality, did not differ from each other in either slope or level. This means that they could be combined into a single linear regression and confirms the results of the previous study (Clausen 1982).

Growth Trends

In the Kansas, Ohio, and Minnesota plantations, height growth during the period from 10 to 15 years after planting continued at the same rates as during the 5- to 10-year interval (fig. 1) while it slowed down in the other 4 plantations. Thus, the growth increment in Michigan and Missouri during the second 5-year period was 76 and 62 percent, respectively, of the increment during the first 5-year period, and it declined to only 24 and 7 percent, respectively, in Illinois and Iowa. As a result, trees in the Michigan and Missouri plantations which were, after 10 years, shorter than those in the Illinois and Iowa plantations now have greater average height.

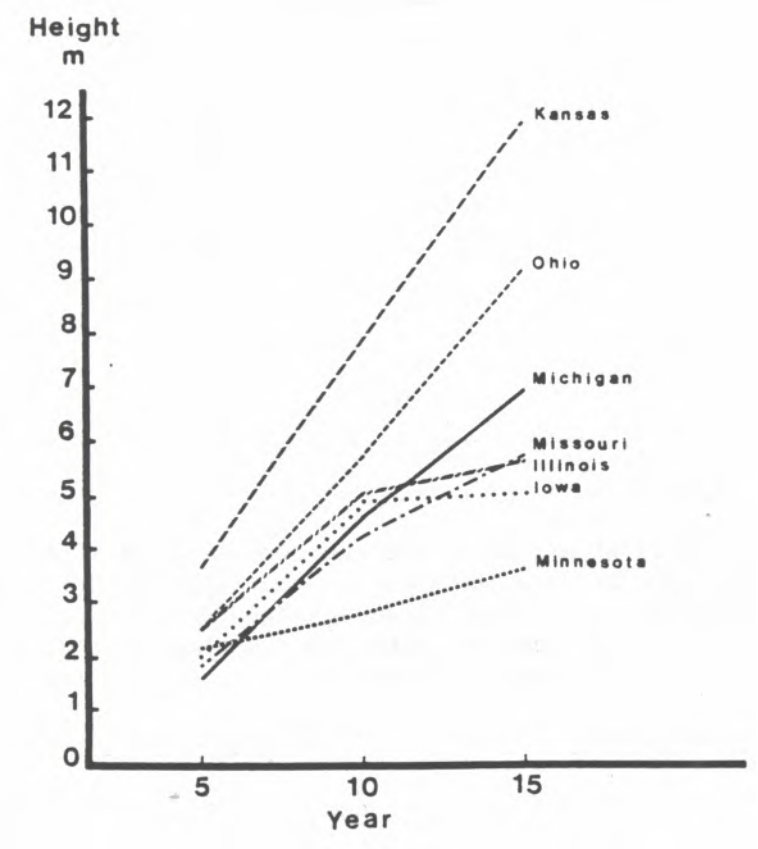

Figure 1.--Average height of black walnut provenances after 5, 10, and 15 years in 7 plantations.

Growth curves of individual provenances differed little in the Missouri, Kansas, Ohio, and Michigan plantations and only moderately in the Illinois plantation. In Iowa and Minnesota, however, height growth of the provenances has decreased during the second 5-year period about in proportion to their origin south of the plantation locations. As a result of origin-related dieback in the Iowa plantation, most provenances from southern Illinois, Virginia, Kentucky, Tennessee, North Carolina, and Texas now are shorter than they were after 10 years in the field (fig. 2). The pattern was similar in the Minnesota plantation where provenances from Missouri, Kansas, southern Indiana, Kentucky,

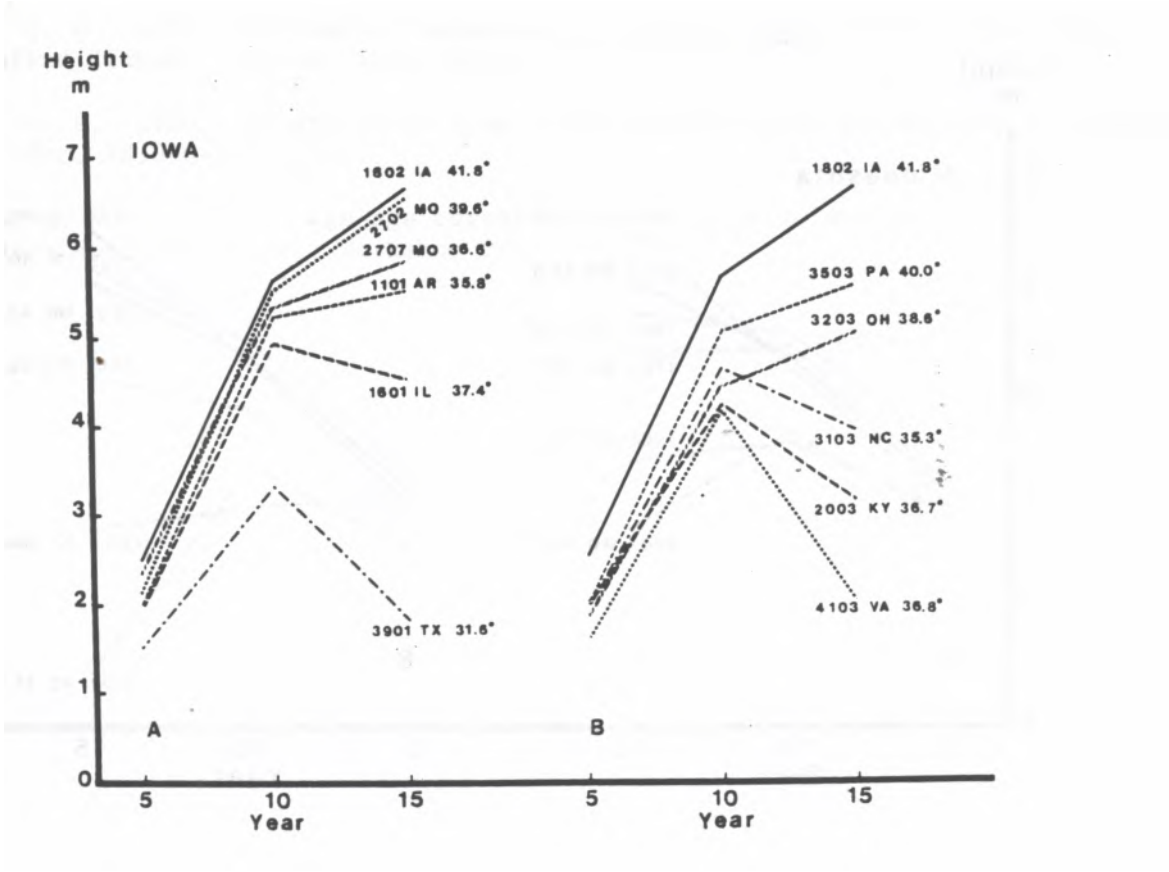

Figure 2.--Height of 5 western (A) and 5 eastern (B) provenances after 5, 10, and 15 years in the Iowa plantation compared with that of the local provenance (1802).

and North Carolina, also were shorter than they were after 10 years (fig. 3). Southern provenances generally lacked winter hardiness in Minnesota where trees from Tennessee and Virginia failed to survive and provenances from North Carolina, Kentucky, and southern Illinois only had 1 or 2 surviving trees. Lack of winter hardiness is also the probable cause of the dieback in the Iowa and Minnesota plantations.

Except for a provenance from Perry County in southern Indiana, which had poor growth and/or survival in all 5 locations where it was planted, the provenances generally did not perform consistently in all test locations. For example, trees from West Virginia that were the tallest in Ohio and Michigan only had average growth in Minnesota. Similarly, trees from Union County, Tennessee, had excellent growth in Ohio but only average growth in Michigan and poor growth in Illinois, Missouri, and Iowa. Texas trees, which continue to be the best performers in Illinois, are the poorest performers in Missouri, Kansas, and Iowa.

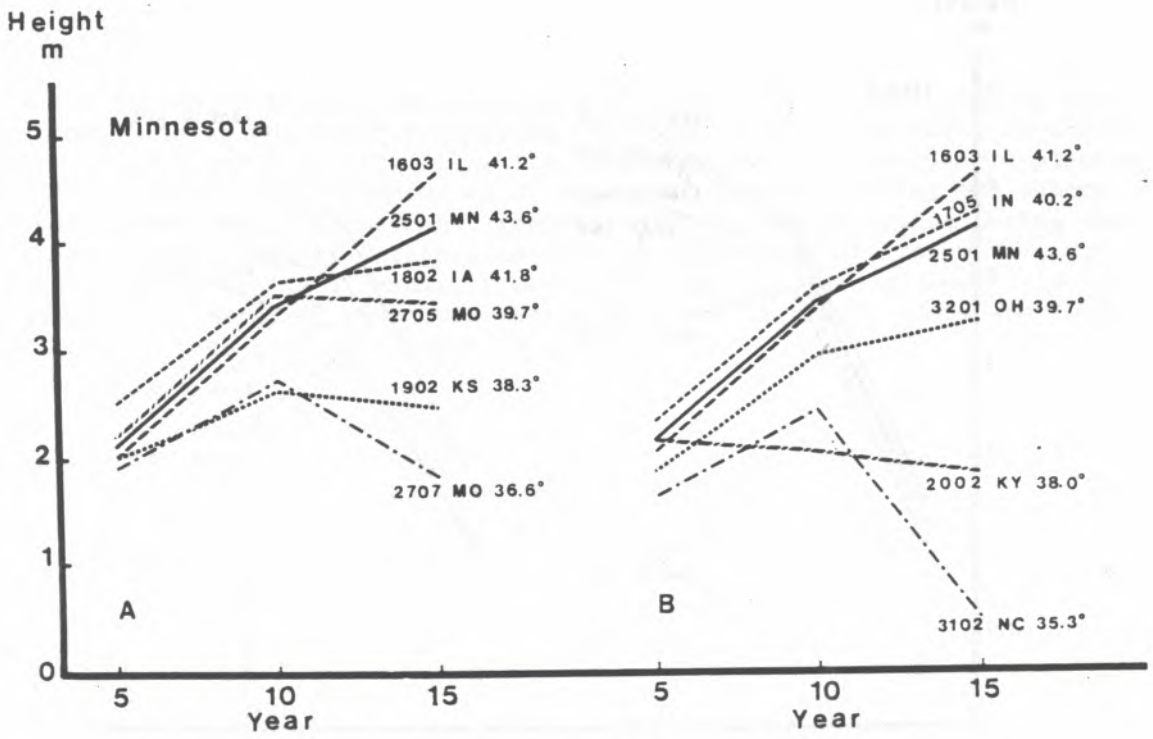

Figure 3.—Height of selected provenances after 5, 10, and 15 years in the Minnesota plantation. Both the group of 6 western (A) and the northwest-southeast transect of 6 (B) include the local provenance (2501).

CONCLUSION

Bey (1980) concluded that sizeable growth gains can be obtained without loss of hardiness in Midwest plantations by moving black walnut provenances as much as 200 miles northward. The current results generally validate that conclusion. Trees originating 200 or more miles south of the plantations have been the best performers in the relatively mild climates of southern Illinois and southern Michigan and appear hardy; thus, it is probably safe to use southern provenances in these areas. The 200-mile rule seems safe for Ohio and probably also for Iowa, as long as mostly western provenances. are used in the latter. Trees of local or near-local origin have had the best growth in Missouri and Kansas but, because provenance differences were not significant in these plantations, other trees originating within the 200-mile zone may grow as well. However, Indiana trees should not be used in Kansas due to poor survival. - Some growth gains appear possible in Minnesota by planting trees from Iowa and northern Illinois, but provenances from more than 200 miles south of the plantation lack hardiness and should be avoided.

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