Performance of Green Ash Seed Sources at Four Locations in the Great Plains Region

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ABSTRACT: *Green ash trees from 10 seed sources were planted in a test in 1961 in four states of the Great Plains Region. After more than 20 years, height growth indicates a strong interaction between seed source and plantation location. Larger trees were from southerly sources within about three degrees of latitude of the plantation site. Beyond those limits, cold injury may result. Height and dbh age-age correlations were highly significant at 8 and 20+ years. Height and dbh correlated negatively with a decrease in latitude. North. J. Appl. For. 22(1):54–58.*

Key Words: Green ash, *Fraxinus pennsylvania*, provenance, Great Plains States.

Green ash (*Fraxinus pennsylvanica* Marsh.) is one of the most widely and successfully planted hardwoods in windbreaks. This species is native on diverse sites east of the Rocky Mountains from southern Alberta, Canada, to Nova Scotia and Florida on the Atlantic coast (USDA Forest Service 1965). Green ash has become increasingly important for urban plantings because of its hardiness and satisfactory performance on adverse sites, even in periodically flooded areas (Broadfoot and Williston 1973).

The importance of the source of tree seed has long been recognized (Bates 1927, Callaham 1964). Provenance studies by Wright (1944) revealed ecotypic variation in winter hardiness, growth rate, leaf fall, and leaf morphology among collections of red ash (now recognized as green ash) from the eastern United States and Canada. Ying et al. (1974) reported a north-south clinal variation in growth rate, bud break, and leaf fall in a nursery study of green ash provenances of the Great Plains region. Meuli and Shirley (1937) found that first-year seedling growth was greatest among the southern sources of green ash. They also found that in the Great Plains region of the United States, the ability of green ash seedling sources to survive drought increased from south to north and from east to west when testing three green ash ecotypes based on resistance to artificially induced drought. Santamour (1963) found tree variation in dieback, mortality, and height growth is as great or greater among trees within provenances than variation among provenances. In a 1975, rangewide study of age six growth (Steiner et al. 1988) found that the tallest sources planted at 10 locations originated from southern Ontario and the "central prairie" regions. Winter injury was important, thus provenances from immediately South of a plantation site were not necessarily the fastest growing in the eastern United States as is often found in provenance studies in North America (Wright 1944).

Little progress has been reported in determining the best green ash source for a particular site. Test plantations have been established in the Great Plains states of Kansas, Nebraska, South Dakota, and North Dakota to determine genetic variability of green ash and to evaluate the adaptability and performance of various seed sources to these plantation sites. The purpose of this article is to report the survival and growth results of four green ash plantings of various provenances in the Great Plains states with the objective of determining better sources for future plantings in the central and northern plains states.

Methods and Materials

The Plant Materials Division, USDA, Soil Conservation Service, collected green ash seed in 1959 from nine native stands in the Great Plains Region which were planted at the Plant Materials Center near Bismarck, ND. The resulting seedlings were supplied to the Nebraska, KS, and South Dakota Agriculture Experiment Stations and the Plant Materials Center, Bismarck, ND (Figure 1) in 1961 to establish provenance tests at four planting locations. A commercial source of unknown location, designated K181, was included in the Manhattan, KS planting. The number of trees in each

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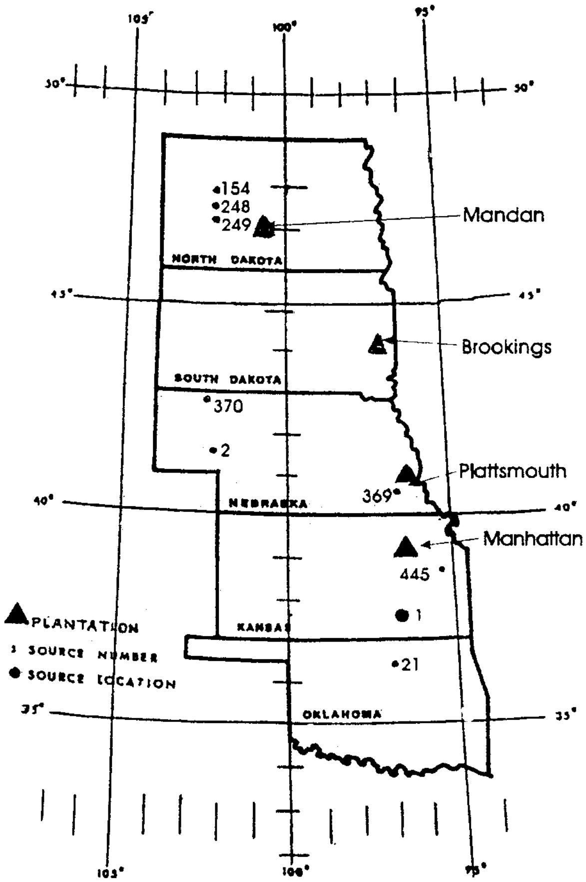

Figure 1. Green ash seed source locations of trees and plantation sites planted in 1961.

stand from which seed was collected was not recorded, but in most instances, seed was probably collected from one to ten trees.

Planting designs were different at each location, as a shortage of planting stock did not allow all sources to be planted at each site. The Mandan, ND planting was on an alluvial soil tentatively classified as Farland loam. The spacing was 6 × 12 ft with five replications of four seed sources in five-tree plots (100 total trees). The Brookings, SD site is on a Dickey soil and was planted at 8 × 8-ft spacing with eight replications of seven seed sources in five-tree row plots (280 total trees). At Horning State Farm, Plattsmouth, NE, the trees from seven seed sources were planted at a spacing of 6 × 12 ft and consisted of four-tree row plots replicated 12 times (336 total trees). The study was established on a severely eroded, upland silty clay loam with a north aspect. The Manhattan, KS planting was on a river bottom with soil classified as Haynie very fine sandy loam. Plantation spacing was 15 × 15 ft, with five replications of five seed sources in one-tree plots (25 trees). Sources that were planted at each location are shown in Table 1. Weeds were controlled by various combinations of cultivation and herbicides as dictated by climate and soil.

The four plantations were measured at various ages (Table 2) when they were of windbreak status and size (at least 20 years of age). Age of measurements was 33 years (1993) at Kansas, 37 years at Nebraska (1997), 41 years at South Dakota (2001), and 22 years at North Dakota (1982). The North Dakota plantation was cut after 22 years.

Table 1. Comparison of total height at eight years among seed sources at each location, expressed as a percent of the plantation mean.

		Plantation location			
		Manhattan KS	Plattsmouth NE	Brookings SD	Mandan ND
Source	Seed origin	-----------(ft.)	-----------		
OK21	Okla. City	—[a]	19.9	7.4	0
K1	El Dorado	20.7	23.6	14.4	3.3
K181	KS comm.	20.9	—	—	—
K445	Ottawa	21.1	—	—	—
NE2	Ash Hollow	17.3	15.9	14.4	9.5
NE369	Syracuse	—	—	15.7	—
NE370	Hays Sprgs.	—	16.2	14.0	11.0
ND154	Killdeer	15.2	14.6	12.4	14.4
ND248	Killdeer	—	15.3	—	—
ND249	Killdeer	—	13.4	13.1	—
Plantation mean (ft)		**19.0**	**17.0**	**13.1**	**8.8**

[a] Not planted

Survival, total height, and dbh (trunk diameter at 4.5 ft) were measured with a fiberglass pole and metal caliper, and relative crown canopy classes were determined. First, the data were analyzed with analysis of variance (ANOVA) for all four plantations together to determine whether any sources grew well at all locations using the SAS PROC MIXED procedure and source means determined by the least squares procedure. Later, each plantation was analyzed separately to determine the best local source as a randomized complete block design, using the SAS General Linear Model procedure (SAS 1996) on an individual tree basis. Duncan's multiple range test was used to separate means for each characteristic. In addition, correlation analyses were applied to height and dbh with latitude and seed source geographic data. Precipitation and elevation data were taken from the weather station nearest the plantation.

Multiple stems were evaluated only at the South Dakota plantation as Kansas and Nebraska were thinned to a single stem.

Results and Discussion

Survival

After 8 years, green ash seedling survival was nearly 100% at all locations except for the Oklahoma source (OK21), which apparently was weakened by winter injury in the nursery bed at Bismarck, SD. Seedlings of the Oklahoma source that survived the first summer at Nebraska and South Dakota were alive after 8 years (1968), but all failed in the North Dakota planting because of winter injury (Table 1).

Overall survival at subsequent measurements (22 to 41 years) at each plantation was 64% in Kansas, 50% in Nebraska, 64% in South Dakota, and 72% in North Dakota, excluding the K1 source, all of which died. Source differences were significant at the 1% level or better. All sources,

Table 2. Mean survival, height, and diameter by source and plantation.[a]

		Plantation location										
		Manhattan KS Age = 33 years (1993)		Plattsmouth NE Age = 37 years (1997)			Brookings SD Age = 41 years (2001)			Mandan ND Age = 22 years (1982)		
Source	Seed origin	Sur.(%)	Ht(ft)	Sur.(%)	Ht(ft)	Dbh(in)	Sur.(%)	Ht(ft)	Dbh(in)	Sur.(%)	Ht(ft)	Dbh(in)
OK21	Okla. City	—[b]	—	31c	45.9ab	9.6a	3c	33.5b	4.5b	—	—	—
K1	El Dorado	80ab[c]	45.0ac	69a	46.9a	9.6a	36b	36.4b	6.2a	0	0	0
K181	KS comm.	20c	47.6a	—	—	—	—	—	—	—	—	—
K445	Ottawa	100a	42.7bc	—	—	—	—	—	—	—	—	—
NE2	Ash Holow	40bc	34.0bd	47abc	40.3bcde	7.1bcde	90a	36.4b	6.1a	88b	18.1b	4.2b
NE369	Syracuse	—	—	—	—	—	65a	35.5b	5.8a	—	—	—
NE370	Hays Sprgs.	—	—	66a	42.8bc	7.3bcd	88a	41.7a	6.1a	100a	22.5a	5.5a
ND154	Killdeer	80ab	35.0bd	40bc	36.9cde	6.2bcde	78a	33.7b	4.8b	100a	20.0b	4.6b
ND248	Killdeer	—	—	62ab	39.0cde	5.7cbe	—	—	—	—	—	—
ND249	Killdeer	—	—	34c	35.4cde	4.8de	88a	35.3b	5.0b	—	—	—
Mean	—	64	40.9	50	41.0	7.2	64	36.1	5.5	72[d]	20.3[d]	4.8[d]
Sign.	—	<1%	<1%	1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%

[a] Source differences for all parameters are significant at the 1% level.
[b] Not planted.
[c] Means separated by different letters are significant at the 5% level.
[d] Mean calculated after excluding the K1 source.

except K181, survived well in Kansas. The best sources in the Nebraska plantation were K1, NE370, and ND248 (Figure 2). The K1 source did not survive well at the two northern locations. Survival of the best sources (NE2, NE370, ND154, NE369, and ND249) in the South Dakota plantation were 65% or greater for trees of all crown classes (Figure 3).

Height

Eight-year-old (1968) height measurements by seed source varied by plantation location (Table 1). Heights of the OK21 source at South Dakota and North Dakota were reduced because of severe winter injury to the crown (Bagley et al. 1970). At this young age in this experiment, the rate of growth was improved without winter injury by moving a seed source north about 3° latitude. Environmental factors apparently became limiting to these sources of

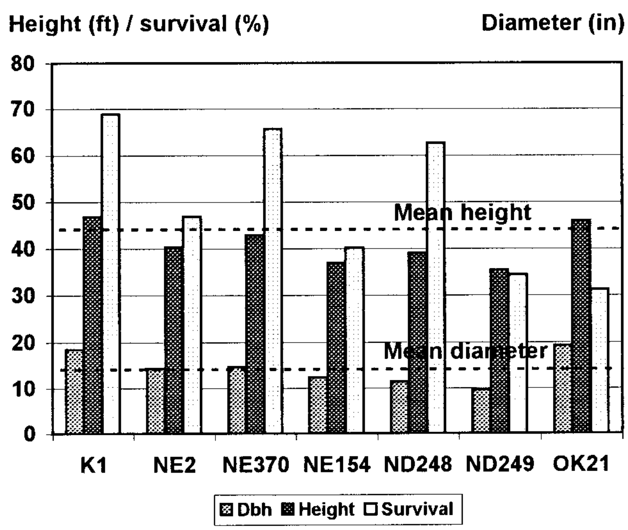

Figure 2. Thirty-seven-year height and diameter measurements by green ash seed sources in Nebraska.

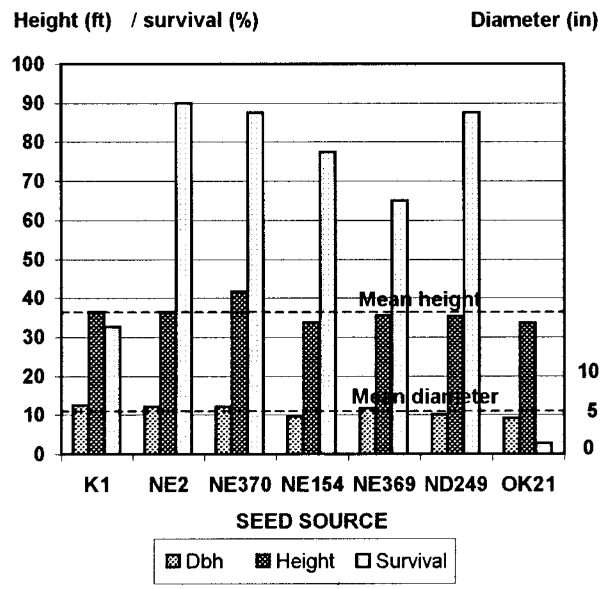

Figure 3. Forty-one-year height and diameter measurements by green ash seed sources in South Dakota.

green ash when they were moved more than 5° north. This is illustrated by the response of the K1 source at Kansas (20.7 ft) to Nebraska (23.6 ft) to South Dakota (14.3 ft in Table 1).

Source differences for height in all the older plantations analyzed together showed no significant difference ($P = 0.1477$), thus no one source was best at all planting locations. Overall mean tree height in the older stands was 40.9 ft at Kansas, 41.0 ft at Nebraska, 36.1 ft at South Dakota, and 20.3 ft at North Dakota (Table 2). Dominant and codominant crown class heights were 5.2 and 3.2 ft taller than the overall plantation means, respectively. Source differences for each plantation were significant at the 1% level for height for all four planting sites. Trees from the Butler

County, KS seed source (K1), were among the fastest growing trees at age 8 years in the 1961 test in Kansas, Nebraska, and South Dakota plantings, but died in North Dakota because of winter injury. Seed source NE370 was tallest in South Dakota and in North Dakota at the older measurement period (Table 2).

Green ash, like many other plants, responds to increased day length with increased rate of growth. Thus, when plants of southern origin are planted in a more northerly latitude, they will produce more total growth during the growing season because the day length for these origins is shorter (Vaartja 1954). However, winter buds may not mature by the date of the first heavy freeze or they may break bud and freeze in a late spring frost; thus winter injury can be severe if the northern migration is too great. A northern source does not use the entire growing season at a more southerly latitude because it is not adapted to a shorter day length. However, in these plantings, northern sources did grow faster in the south than they did in the north, perhaps due to other environmental factors, such as warmer temperatures during the growing season.

The apparent ability of northern sources of green ash to grow faster than southern sources where water is often limited was reported by Mueli and Shirley (1937) and suggests that drought resistance of green ash increases with latitude of origin.

Diameter

Seed source accessions in the older stands performed very much like they did at age 8 years, having similar relative sizes; the tallest and largest diameter trees ranked were similar (Tables 1 and 2). At older ages, the sources with the largest diameters were those with the tallest heights (r = 0.757, 1% level). Combined data for all plantings showed no significant differences among sources for diameter (Pr = 0.4117). The OK21 was the largest in Nebraska, while source K1 was the largest in South Dakota and NE370 in North Dakota (Table 2). Overall mean tree diameters in the older stands were 7.2 in. at Nebraska, 5.5 in. at South Dakota, and 4.8 in. at North Dakota. Trees in the dominant and codominant crown classes had diameters that were 1.9 and 1.7 in larger, respectively, than the plantation means.

Multiple Stems

At eight years of age at Nebraska, two or more stems occurred more often among the trees from the Kansas and Oklahoma sources than among those from the northern sources, even though there had been no apparent winter injury. Another possible cause for this may be animal damage, although not recorded. Two or more stems, at this young age, were more prevalent among southern origins at North Dakota and Nebraska. At the older ages all plantations except the South Dakota location were thinned to one main stem. Analysis of the South Dakota plantations found significant differences (1% level) with source means of 1.23 to 1.62 stems / tree, but no latitudinal trend. Thirty percent of the trees had two or more stems. Only one North Dakota source, ND369, had a large number of multiple stems, 50% of the trees.

Correlation Analysis

A general relationship exists between latitude of the plantation sites and overall plantation means. At age 8 years the southern sources (K1, NE2, and NE370) appeared to be sensitive to latitude (Table 1). At older ages, the northern sources grew better in the southern plantations than they did in the north. The age-latitude correlations for height were $r = -0.44$ and for diameter $r = -0.47$ at eight years.

In this study, selection of trees at age 8 years for good height growth at older ages is a reliable predictor (r = 0.71) of a tree's potential (Table 3). A 20-year–old green ash provenance test in Kansas showed that height at 5 years was not indicative of later growth, but at age 12 the relationship improved substantially (r = 0.83) (Bresnan et al. 1996). Diameter growth in the current ash study paralleled height growth. The taller green ash trees had greater diameters (r = 0.54).

Both total height and dbh were negatively related to the latitude of the seed sources (Table 3). Sources from the southern latitudes (range 35–42°) were taller than those from northern climes (height, r = −0.45** and dbh, r = −0.51*). Both precipitation and elevation were highly correlated with latitude; precipitation (−0.87**) and elevation (0.62**). Annual precipitation was highly correlated with elevation (−0.88**).

Conclusion

Fast-growing trees are desired in windbreak plantings if the trees have other desirable characteristics. Trees from southern sources were taller than those from northern sources, thus confirming the generally recognized concept of clinal variation in which the fastest growth often occurs from southerly sources.

We found latitudinal differences, but not elevational or precipitation differences. In this study, the rate of growth was improved without winter injury by moving a seed source north about three degrees latitude. The K445 source appears suitable for planting in Kansas while the K1 source is suitable in Kansas, Nebraska, and South Dakota. Sources Nebraska 370, NE 2, and ND248 are also desirable for Nebraska. All of the tested sources other than OK21 grew well in South Dakota. North Dakota should favor planting

Table 3. Correlation of height with dbh at two different time intervals and geographic characteristics for green ash.

Variable	Height or diameter	Geographic		
Height	H 1982+	Lat.	Precip.	Elev.
1968 (8 yr)	0.71**[a]	−0.44*	0.46 ns	−0.27 ns
1982+ (22 to 41 yr)		−0.45*	0.32 ns	−0.10 ns
Dbh	D 1982+	Lat.	Precip.	Elev.
1968 (8 yr)	0.55**	−0.47*	0.50*	−0.28 ns
1982+ (22 to 41 yr)		−0.51*	0.38 ns	−0.15 ns
Geographic			Precip.	Elev.
Latitude			−0.87**	0.62**
Annual precip.				−0.88**

[a] Significant at 5% level (*), at 1% level (**), nonsignificant (ns).

of NE2, NE370, and ND154. Trees from Oklahoma should not be planted in states to the north.

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