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Juniper Seed Sources in the Great Plains

Richard A. Cunningham and Rudy M. King

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ABSTRACT

At age 10, 100% of eastern redcedar (L.) and Rocky Mountain juniper (Sarg.) trees from several seed sources throughout the Great Plains had survived. Seed sources from southeastern Texas had the poorest survival. Eastern redcedar trees from Kansas seed sources grew tallest, and trees from Montana and southeastern Texas seed sources were the shortest. Rocky Mountain juniper trees survived better, were shorter, had smaller crowns, exhibited greater damage from Cercospora blight ((Ellis and Everh.) Sutton and Hodges, formerly var.) and Kabatina tip blight (Schneider and V. Arx) and less damage from cedar-apple rust than did eastern redcedar trees. Eastern redcedar trees were larger, had more horizontal branching, and exhibited a greater incidence of cedar-apple rust and bagworm. In the northern Great Plains, trees from seed sources 1 to 4 ° latitude south of each test site survived best and grew the tallest. In the central Great Plains, trees from seed sources from 1 to 4 ° latitude north of each test site survived best, while those from 4 ° latitude north and 6 ° longitude east grew the tallest. Cluster analyses differentiated groups of seed sources that performed in a similar manner in terms of survival, height, and crown characteristics. Although most clusters were composed of seed sources from the same species and geographic area, one cluster contained seed sources of both species and ranked near the median for most traits. Age/age correlations indicated that seed sources may be successfully selected for good survival and fast growth rate at age 5.

Keywords: Rocky Mountain juniper, eastern redcedar, planting stock, seed sources, Great Plains, survival, height, and crown characteristics

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Juniper Seed Sources in The Great Plains

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Application

Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) and eastern redcedar (*J. virginiana* L.) were extensively planted in windbreaks and other conservation tree plantings throughout the Great Plains. The seed sources used by nurseries growing seedlings for these plantings were generally chosen on the basis of availability, rather than adaptability or performance potential. Determining and choosing the best seed source to produce planting stock for specific planting sites would improve the survival and performance of these species in windbreak and conservation plantings throughout the Great Plains.

Introduction

Information about the genetic variation among populations of Rocky Mountain juniper or eastern redcedar has been limited to taxonomic studies of the distribution of each species, and their hybrids, within the Great Plains. Studies by Fassett (1944), Hall (1952), Van Haverbeke (1968), Schurtz (1971), von Rudloff (1975), Flake et. al. (1978), Comer et. al. (1982), and Adams (1983) characterized junipers in the Great Plains as a variable population, probably due to introgressive hybridization. Variation was expressed in a gradual transition throughout the region. Van Haverbeke (1968) identified a zone of transition from southwestern South Dakota to northeastern Colorado. Trees to the north and west of this zone were typical of Rocky Mountain juniper, in most traits. For most traits, trees to the south and east of this zone were typical of eastern redcedar in most traits. Very little was known about the adaptability of *Juniperus* seed sources to specific planting sites throughout the Great Plains. In particular, whether nonlocal seed sources would perform as well or better than local seed sources.

In 1973, the GP-13 Technical Committee of the Great Plains Agricultural Council initiated a cooperative seed-source study of Rocky Mountain juniper and eastern redcedar. The objectives of the study were to: 1) determine the genetic variation of major traits exhibited by both species; 2) identify the best sources of seed for the production of planting stock for use in each state; and 3) provide germplasm of known parentage for use in selection and breeding programs.

Materials and Methods

Seed Collection

Field personnel of the USDA Soil Conservation Service (National Resource Conservation Service), USDA Forest Service, state universities, and state forestry agencies collected cones from 275 eastern redcedar and Rocky Mountain juniper trees in natural stands and windbreaks throughout the Great Plains (figure 1). Seed trees that had favorable windbreak characteristics were selected. The sampling scheme was based on seed zones proposed by Cunningham (1975). Cones were packaged in single-tree lots and shipped to the Forestry Sciences Laboratory, Lincoln, NE where seed was extracted and placed in -16 °C storage.

Test Site Establishment

In mid-August 1977, seed lots were sown in nursery beds at the USDA Forest Service Bessey Nursery near Halsey, NE. In March 1980, 2-year-old seedlings were shipped to 12 test-site cooperators throughout the Great Plains. Not all seed sources were planted at each site. Sites were stratified geographically into 3 regions (northern, central, and southern) and identical sets of seed sources were established at each site within the region. A randomized complete block with 5 replications of 4-tree, linear plots was established at each test plantation.

After 5 growing seasons, survival and height data were collected and reported by Van Haverbeke and King (1990). At the Plattsmouth, NE site, a second test plantation including 131 eastern redcedar seed sources and 25 Rocky Mountain juniper seed sources was established to study diseases (Zhang et al., 1997). In this planting, all the plots were inoculated for Cercospora blight in 1982, 1984, 1985, and 1986. Cercospora blight was recorded in 1987; Kabitina tip blight occurred naturally, and was also recorded.

Data Collection

In 1989, tenth-year data was collected at 8 sites (Bridger, MT; Towner, ND; Mandan, ND; Brookings, SD; Plattsmouth, NE; Hastings, NE; Colby, KS; Sacville, MO) (figure 2). Data collected included survival, height, crown width,

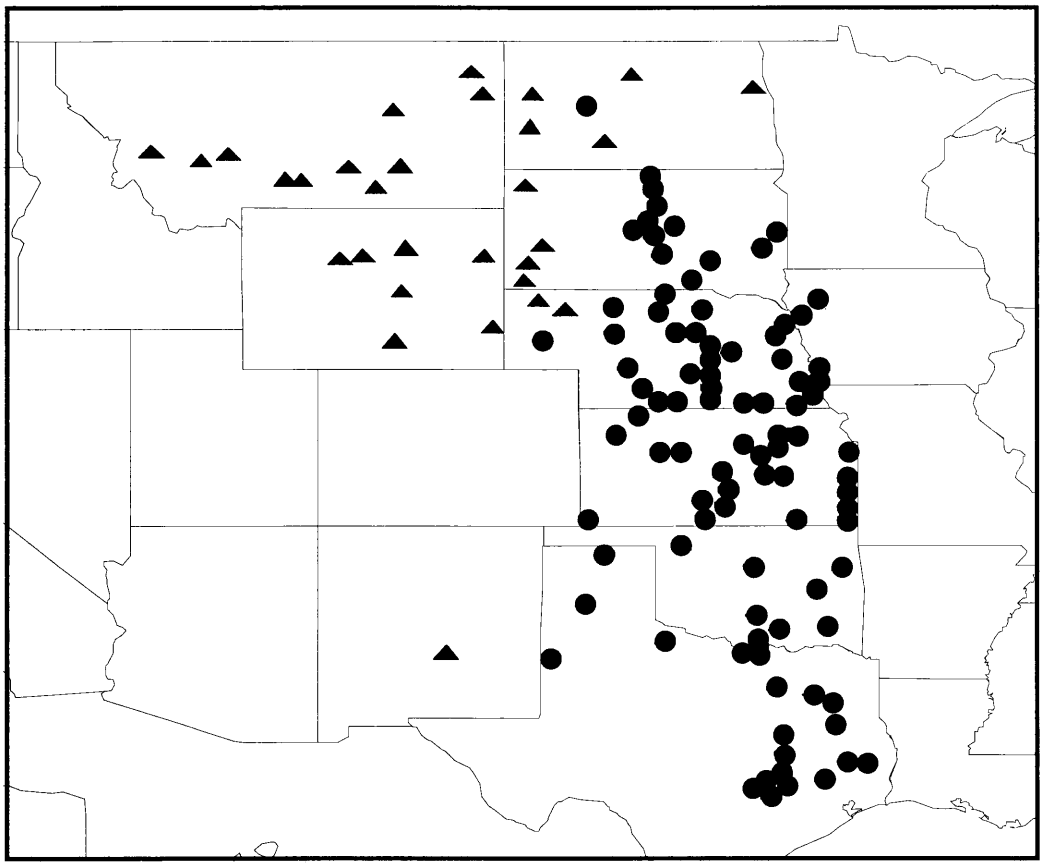

Figure 1. *Juniperus virginina* (●) and *J. scopulorum* (▲) seed sources sampled in the study.

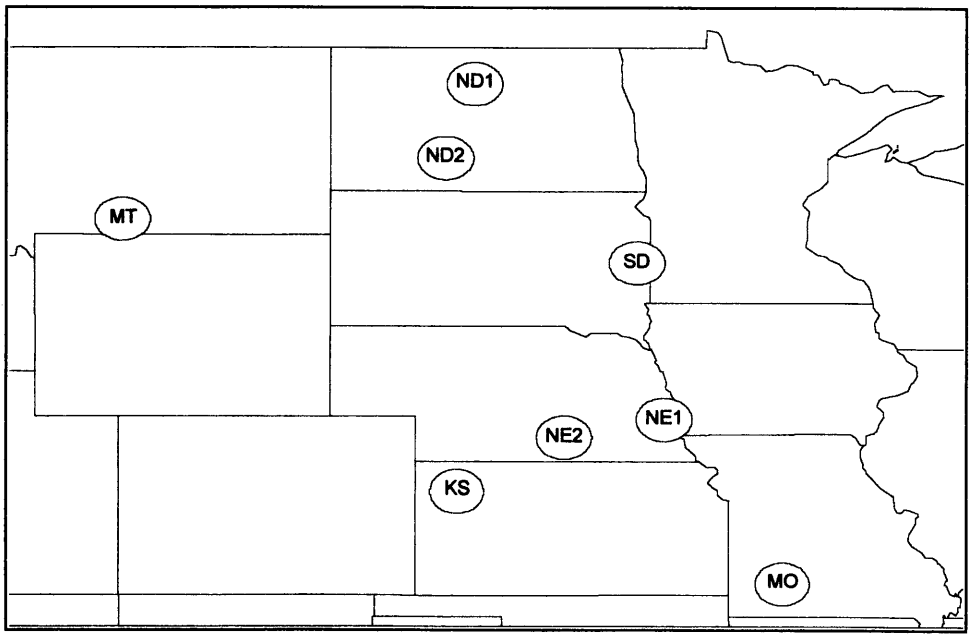

Figure 2. Locations of test plantations.

crown density, branch angle, sex, strobili production, and pest incidence[1]. Cedar-apple rust (*Gymnosporangium juniperi-virginianae*) and Cercospora blight were recorded in the South Dakota, Nebraska and Missouri sites. Kabatina tip blight occurred only in the Missouri and Nebraska sites. Bagworms (*Thyridopteryx ephemeraeformis*) were only recorded in the Missouri site. Schaefer (1995) has previously reported on the 10-year results of the test site in South Dakota.

Statistical Analyses

Statistical analyses were performed with SAS software (Statistical Analysis System, SAS Institute Inc., Cary, NC) and SPSS software (SPSS Inc., Chicago, IL). Analyses of site and species differences necessitated dropping 2 sites (Bridger, MT and Sacville, MO), which did not contain at least 121 seed sources as did the remaining 6 test sites. Mean responses for the 121 seed sources that were planted at all 6 test sites were initially analyzed in a 2-way analysis of variance of site and species. However, site-by-species interactions were strong in all analyses, and assumptions of normality and homogeneous variance were questionable. Therefore, the eastern redcedar and Rocky Mountain juniper were compared separately for each site using a Wilcoxon-Mann-Whitney rank test (Siegel and Castellan 1988). Sites were compared separately for each species using a Kruskal-Wallis rank test (Siegel and Castellan 1988) followed by a Tukey modification of Dunn's procedure to specify pair-wise site differences (Hochburg and Tamhane 1987). Significance levels and multiple comparison procedures were adjusted using a Bonferroni correction to maintain Type I error at 0.05 for each set of analyses (Miller 1981). Categorical modeling was used to examine the pest scores (Rust, Cerc, Kab, Bag) for those sites where they were recorded.

Cluster analyses (Ward's minimum variance) were used to identify seed sources with similar performance characteristics across the test plantations. Variables used in those analyses were survival, height, crown width, crown density, branch angle, and number of terminals. Only seed sources present in all 6 test sites were included in the analysis. Genotype x environment interaction was examined by a 2-factor analysis of variance with clusters and plantations as factors.

[1] *Data were measured or scored as: survival (%); height (cm); crown width (cm); crown density (very sparse = 1, sparse = 2, moderate = 3, dense = 4, very dense = 5); branch angle (acute < 30°, moderate = 30° - 60°, horizontal > 60°); sex (male, female, both); strobili production (none = 1, few = 2, moderate = 3, many = 4); and pest incidence (absent = 1, light = 2, moderate = 3, heavy = 4, very heavy = 5).*

Provenance transfer models for each test plantation were estimated from least squares regression of differences in latitude, longitude, and elevation between source locations and plantation locations.

Simple Pearson correlations were computed among seed source means for each trait at each test site. The correlation of each trait with species, latitude, and longitude was also examined with simple Pearson correlations. Categorical variables were assigned ordered, equally-spaced values.

The value of the 5-year regression model in predicting the 10-year height at each test site was examined by adjusting the constant in the 5-year model to reflect the 10-year mean height. Residuals for the difference between the calculated and the actual 10-year heights were calculated using the 5-year and the 10-year regression models. A univariate analysis was performed to characterize the mean residuals for each model at each test site.

To determine the reliability of early seed source selection, age/age correlation was computed for survival and height of 4-tree plots at ages 5 and 10.

Results

Site - Species Analysis of Variance

Survival

Mean performance at all 8 test sites is shown in table 1. Table 2 lists the means by site and species for the 6 sites included in the site-species analysis of variance. The 2 species did not differ significantly in survival except at Plattsmouth, NE where eastern red cedar survived better than Rocky Mountain juniper (table 2). Within respective species, Rocky Mountain juniper survived best at Hastings, and eastern redcedar survived best at both Nebraska sites.

Height

Eastern redcedar grew taller than Rocky Mountain juniper at each site except Towner, ND where no significant difference was apparent. Within species, eastern redcedar grew tallest in Nebraska and shortest at Towner, ND.

Crown Width

Eastern redcedar had a significantly greater crown width than Rocky Mountain juniper at each test site. Within each species, eastern redcedar was widest at Plattsmouth, NE and Colby, KS. Rocky Mountain juniper was widest at Colby, KS and narrowest at Towner, ND.

Table 1. Mean performance by site averaged over all seed sources.

Site	Surv[a]	Ht[b]	Cw[c]	Term[d]	Cd[e]	Angle[f]	Strob[g]	Rust[h]	*Cerc*[i]	Kab[j]	Bag[k]
	%	cm	cm	no				score			
Bridger, MT	97	231	226	1.5	3.6	2.0	2.9	—	—	—	—
Towner, ND1	77	151	176	1.8	2.8	1.7	2.9	—	—	—	—
Mandan, ND2	77	274	200	2.7	3.8	1.8	3.4	—	—	—	—
Brookings, SD	73	239	209	1.5	2.9	1.7	2.7	0.6	0.1	—	—
Plattsmouth, NE1	92	369	292	1.3	3.5	2.0	1.7	0.6	1.4	1.4	—
Hastings, NE2	95	305	246	1.4	3.6	2.0	1.8	0.2	0.3	0.7	—
Colby, KS	79	286	289	1.3	3.6	1.8	2.6	—	—	—	—
Sacville, MO	69	289	170	1.2	2.2	1.9	1.0	0.9	3.2	0.4	1.0
All	82	275	234	1.6	3.3	1.9	2.4	0.4	0.9	0.9	1.0
S. E.	0.8	2.6	2.2	0.02	0.02	0.01	0.03	0.01	0.05	0.03	0.02
N	1094	1055	1055	1055	1055	1055	1055	705	569	439	79

[a]survival; [b]height; [c]crown width; [d]terminals; [e]crown density; [f]branch angle; [g]strobili; [h]cedar-apple rust; [i]Cercospora blight; [j]Kabatina blight; [k]bagworm.

Table 2. Means by site and species for the 6 sites in the site-species analysis.

Site	Species	Surv	Ht	Cw	Term	Cd	Angle	Strob
		%	cm	cm	no		score	
Towner, ND	ERC[a]	81	154	187	1.8	2.6	1.9	3.0
	RMJ[b]	87	147	146	1.7	3.4	1.3	2.0
Mandan, ND	ERC	83	288	215	2.5	3.5	1.9	3.5
	RMJ	86	262	174	2.5	4.5	1.5	3.5
Brookings, SD	ERC	82	246	224	1.5	2.8	1.8	2.9
	RMJ	89	230	173	1.6	3.3	1.2	2.1
Plattsmouth, NE	ERC	97	411	334	1.2	3.8	2.0	1.9
	RMJ	89	258	162	1.7	2.9	2.0	1.1
Hastings, NE	ERC	98	350	286	1.2	3.9	2.1	1.9
	RMJ	96	242	175	1.8	3.3	2.0	1.8
Colby, KS	ERC	85	308	320	1.3	3.5	2.0	3.1
	RMJ	87	269	255	1.4	4.5	1.1	2.0
	All	88	280	244	1.6	3.4	1.9	2.6
	S.E.	0.7	3.3	2.7	0.03	0.02	0.01	0.03
	N	726	726	726	726	726	726	726

[a] eastern redcedar.

[b] Rocky Mountain juniper.

Crown Density

Rocky Mountain juniper had significantly denser crowns than eastern redcedar at each test site, except at Plattsmouth and Hastings, NE. Comparing sites within each species, eastern redcedar was densest at both Nebraska sites and least dense at Towner, ND and Brookings, SD. Rocky Mountain juniper was densest at Mandan, ND and Colby, KS.

Terminals

The species differed significantly in the number of terminals only at the Nebraska sites where Rocky Mountain juniper had the greater number of terminals. Comparing sites, within species, Rocky Mountain juniper had the most terminals in Mandan, ND and the least in Brookings, SD and Colby, KS. Eastern redcedar had the greatest number of terminals at the North Dakota sites and the least at the Nebraska and Kansas sites.

Branch Angle

At each test site, eastern redcedar had a significantly greater branch angle than Rocky Mountain juniper. Comparing sites, within species, eastern redcedar at Plattsmouth, NE and Hastings, NE had greater branch angles than Mandan, ND and Colby, KS. Brookings, SD and Towner, ND had the least branch angles. Rocky Mountain juniper at Plattsmouth, NE and Hastings, NE had greater branch angle than at any other sites.

Strobili

The species differed significantly in strobili production at each site, except Hastings, NE. Comparing sites, within species, Rocky Mountain juniper had the most strobili at Mandan, ND and the least at the Nebraska sites. Eastern redcedar had more strobili at Towner, ND and Mandan, ND and the least at both Nebraska sites.

Pest Scores

Cedar-apple rust and Cercospora blight were most prevalent in the Missouri plantation, while *Kabatina* blight was most severe in the Plattsmouth, NE plantation. Bagworms (*T. ephemaraeformis*) were recorded only in the Missouri plantation.

Seed Source Means Averaged Over All Sites

Averaged over 8 test sites, several seed sources had a survival rate of 100%. Seed sources with perfect survival were scattered throughout most of the Great Plains states. Seed sources from Texas exhibited the poorest survival (< 30%), with a source from Smith County, TX surviving at only 11%. Overall survival was 82% (table 1).

Four of the 5 tallest seed sources were from Kansas. The fifth-tallest was from Fourd county, in northwest Texas. Ironically, 5 of the 7 shortest seed sources were from counties in southeast Texas. The other 2 of the 7 shortest seed sources were from Montana.

Means for crown width mirrored those for heights with 4 Kansas seed sources among the 5 seed sources averaging the widest crown width. Seed sources with the narrowest crowns included those from both Rocky Mountain juniper (WY) and eastern redcedar (TX). Seed sources with the greatest crown density were eastern redcedar sources from North Dakota, Oklahoma, and Kansas. An exception was a Rocky Mountain juniper source from South Dakota. The least dense crowns were typical of seed sources from Texas and Oklahoma. Seed sources with the fewest terminal shoots were from Kansas, Nebraska, and South Dakota. Seed sources from Texas and Oklahoma had the greatest number of terminal shoots, probably as a result of winter damage in the more northern test sites.

Most of the seed sources with the most acute branch angle were Rocky Mountain juniper from Wyoming, Montana, and North Dakota. More horizontal branching habit was typical of seed sources from Texas, Oklahoma, Kansas, and South Dakota.

Rocky Mountain juniper seed sources from Wyoming, Montana, and North Dakota had the least incidence of cedar-apple rust, whereas seed sources of eastern redcedar from Kansas, Nebraska, and South Dakota had the greatest incidence. Cercospora and Kabatina blights were most severe on Rocky Mountain juniper seed sources from Montana, North Dakota, South Dakota, and Wyoming. In a separate inoculation study at the Plattsmouth, NE site, this same trend was reported (Zhang et al., 1997). Seed sources from southeastern sites at lower elevations exhibited higher resistance to Cercospora and Kabatina blight than seed sources from northwestern sites at higher elevation.

Incidence of bagworm was greatest on some eastern redcedar seed sources from Nebraska, while other Nebraska seed sources had very little damage. Rocky Mountain juniper seed sources from Wyoming, Montana, and North Dakota had no incidence of bagworm damage.

Seed Source Performance at Individual Test Sites

Significant differences among seed sources existed at each test site for survival, height, crown width, crown density, and branch angle. Number of terminals differed significantly among seed sources at all sites except South

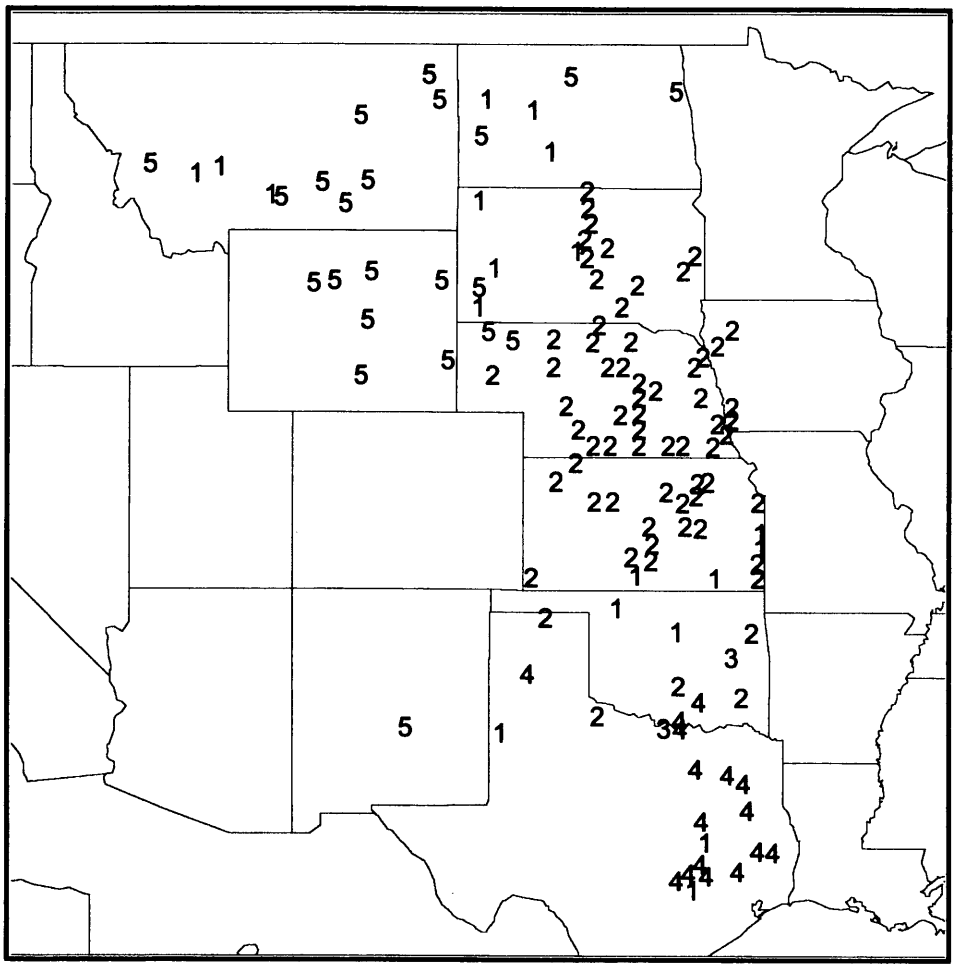

Figure 3. *Juniperus* seed-source clusters as determined by cluster analysis.

Dakota. At sites where they were recorded, significant differences among seed sources existed for Cercospora blight, Kabatina tip blight, cedar-apple rust, and bagworm. Instead of focusing on site-specific results, we chose to look for more general patterns of variation using cluster analysis.

Cluster Analysis

The cluster analysis included 121 seed sources that were present in all 6 test sites. The analysis differentiated 5 clusters composed of seed sources that performed similarly in terms of survival, height, crown width, crown density, branch angle, and number of terminals. These clusters were not geographically distinct in all cases (figure 3).

Cluster #1 was a disjunctive combination of eastern redcedar from Kansas, Oklahoma, and Texas, and both species from Montana, North Dakota, and South Dakota (figure 4). Survival of Cluster #1 seed sources averaged 80% over all plantations (figure 5), with highest survival occurring in the central plains (figure 6). Height growth of cluster #1 seed sources was greatest in Nebraska and poorest in Mandan, ND (figure 7). Among the 5 clusters, cluster #1 seed sources ranked second for mean height growth and mean crown width, and fourth for mean crown density (figures 5, 8). Mean number of terminals ranked second highest and branch angle was intermediate (figure 9).

Cluster #2 seed sources were all eastern redcedar and were scattered over the Great Plains from South Dakota to Texas (figure 10). Survival, height, and crown width of these seed sources ranked highest among the 5 clusters (figure 8). Crown density tied for second place (figure 8). Mean number of terminals ranked lowest and branch angle tied for highest (most horizontal) among the 5 clusters (figure 9). Survival and height ranked highest at all sites and was best in Nebraska (figures 6, 7).

Cluster #3 consisted of only 2 seed sources and both were eastern redcedar from Oklahoma and northern Texas

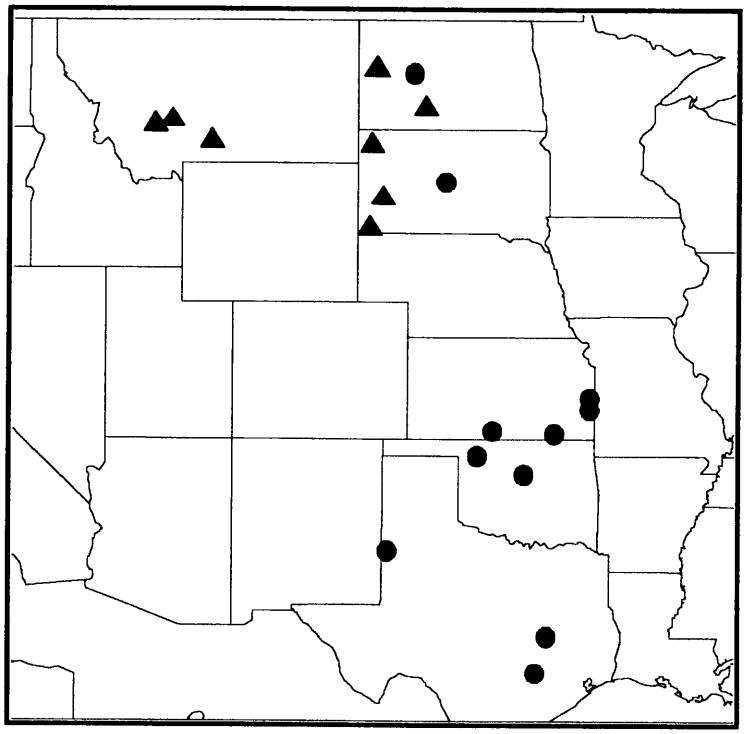

Figure 4. *Juniperus* seed sources in cluster #1 (▲ = *J. scopulorum*; ● = *J. virginiana*).

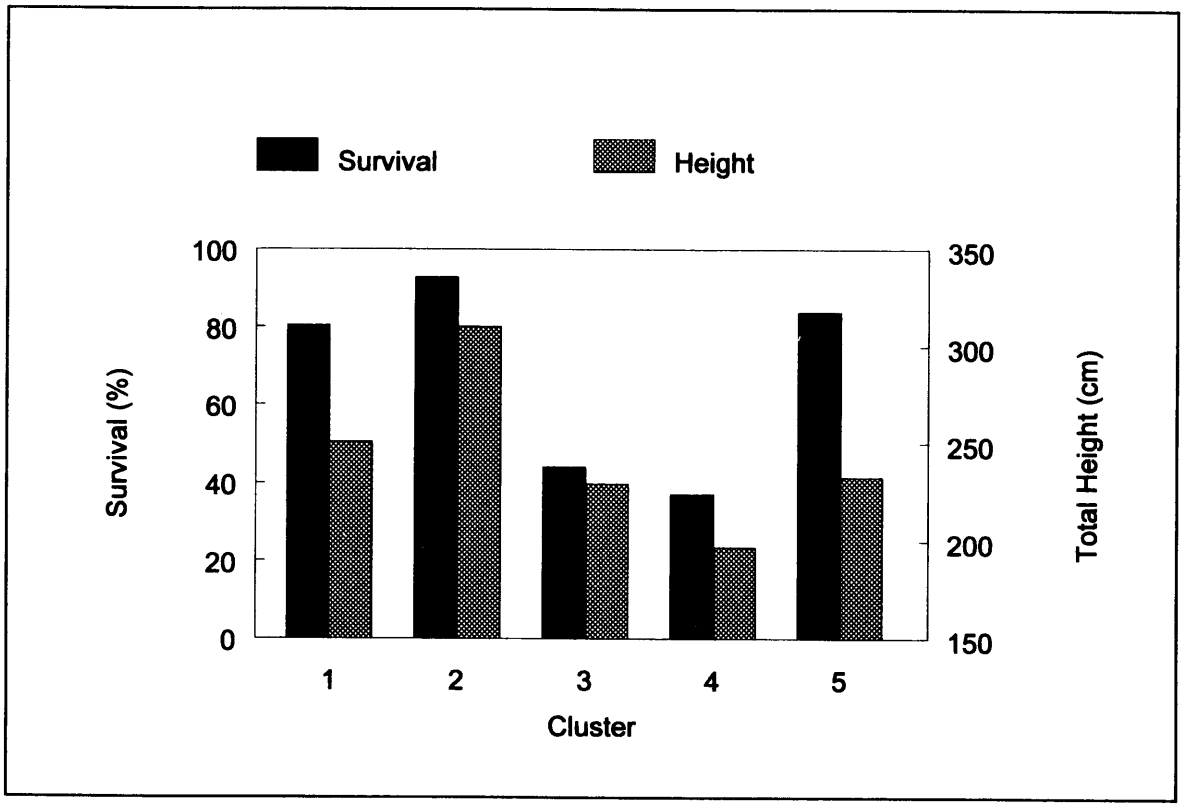

Figure 5. Mean survival and height of *Juniperus* seed-source clusters.

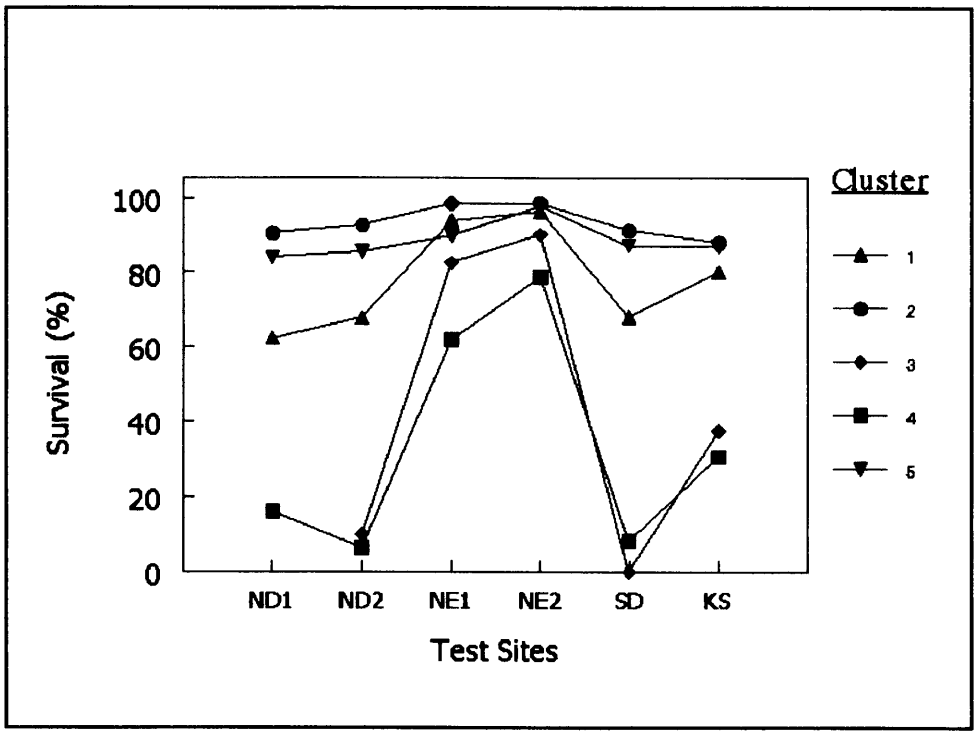

Figure 6. Genotype x environment interactions for survival (seed-source clusters vs. test sites) of *Juniperus* in the Great Plains.

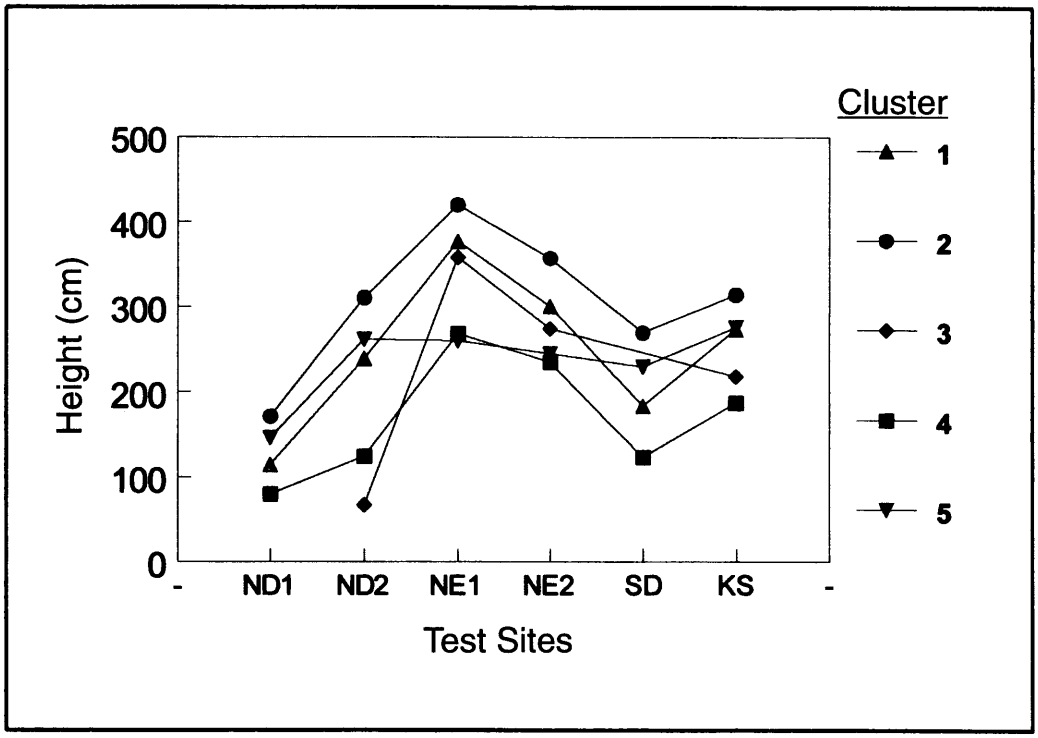

Figure 7. Genotype x environment interactions for height (seed-source clusters vs. test sites) of *Juniperus* in the Great Plains.

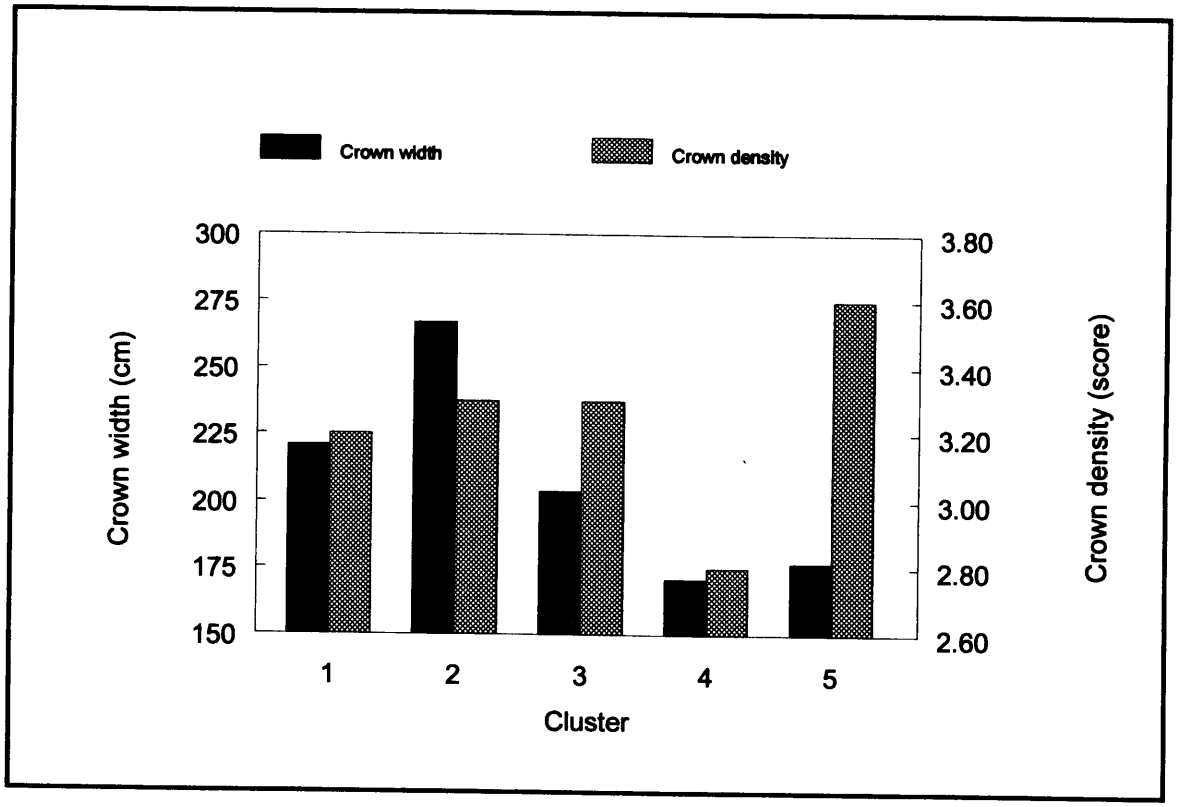

Figure 8. Mean crown width and crown density of *Juniperus* seed-source clusters.

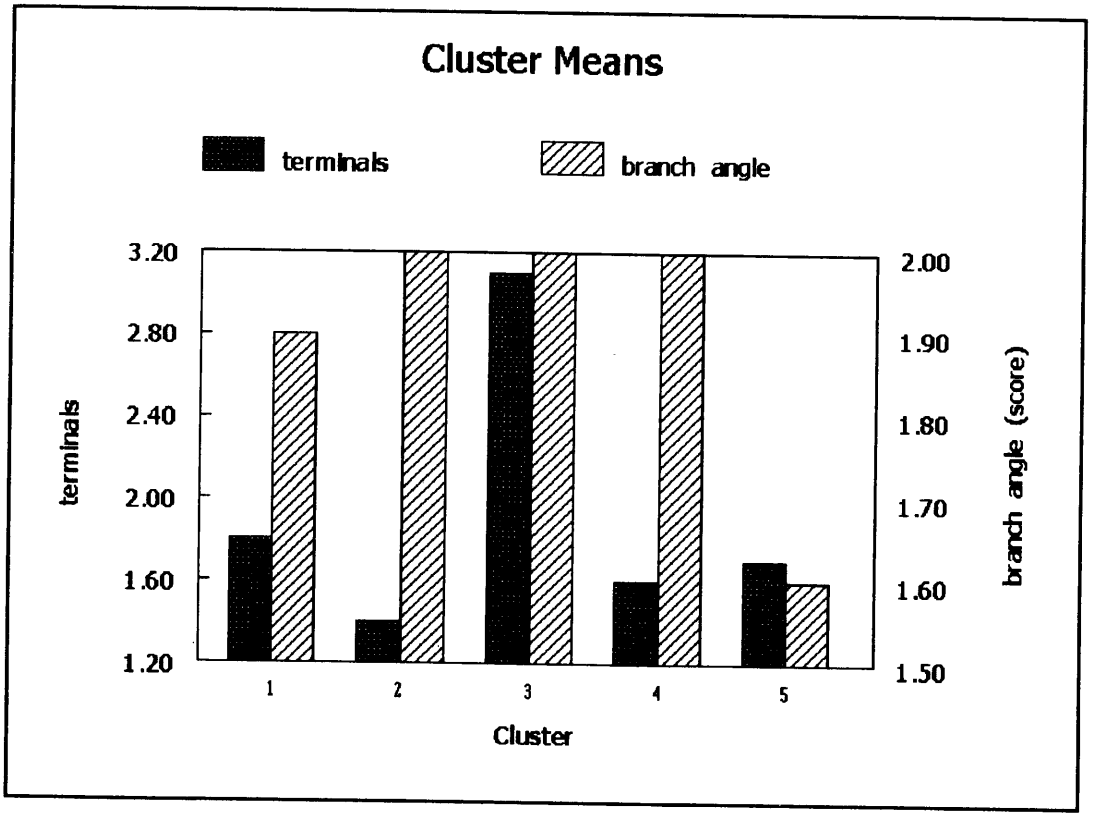

Figure 9. Mean number of terminals and branch angle of *Juniperus* seed-source clusters.

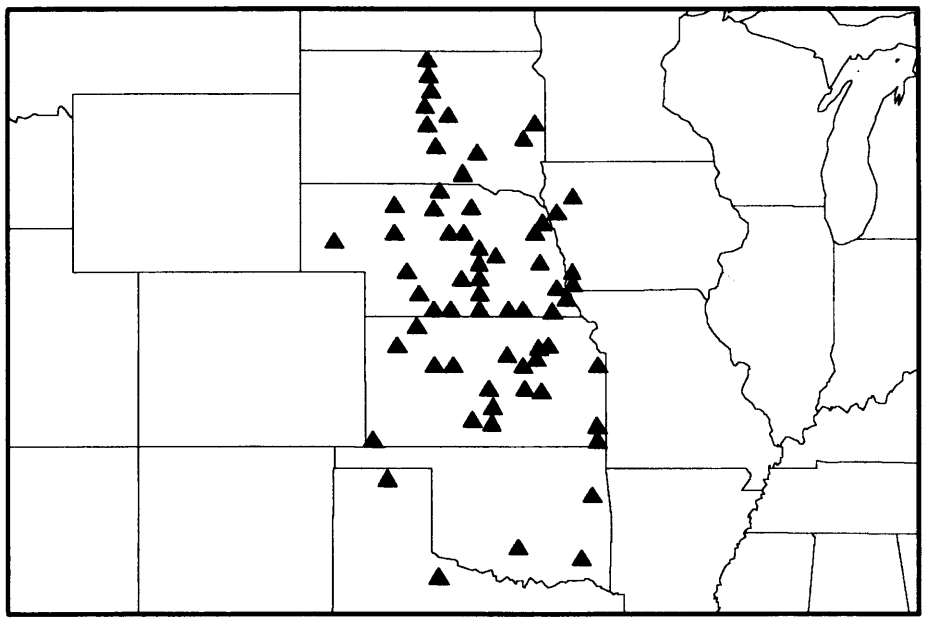

Figure 10. *Juniperus* seed sources in cluster #2 (▲ = *J. scopulorum*).

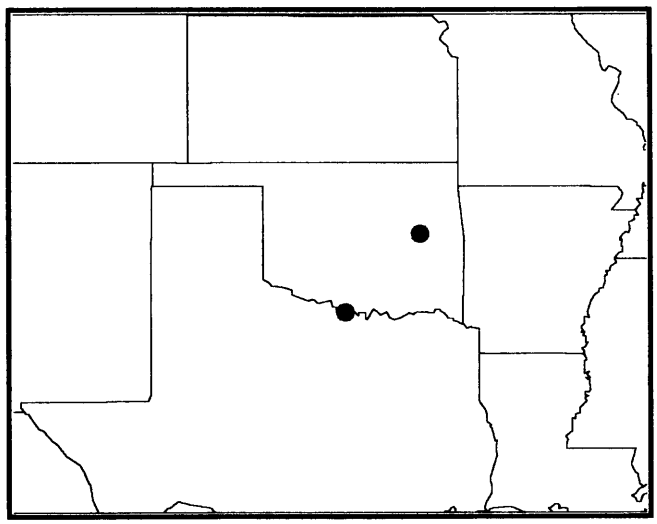

Figure 11. *Juniperus* seed sources in cluster #3 (● = *J. virginiana*).

(figure 11). These seed sources were intermediate in survival, height, and crown width (figures 5, 8), but were above average in crown density, number of terminals, and branch angle (figures 8, 9). Survival of these seed sources was best in Nebraska, but very poor in North Dakota and South Dakota (figure 6).

Cluster #4 seed sources were all eastern redcedar from Oklahoma and Texas (figure 12). Survival, height, crown width, and crown density (figures 5, 8) ranked lowest among the 5 clusters, while the number of terminals was intermediate and the branch angle was tied for the most horizontal (figure 9). Survival was highest in Nebraska, and poor at all other sites (figure 6). Height growth of these clusters ranked lowest at most sites and was second lowest at one North Dakota site (ND2).

Cluster #5 was entirely Rocky Mountain juniper seed sources from the northern Great Plains, and one from New Mexico (figure 13). Overall, these seed sources ranked second best in survival and intermediate in height (figure 5). Crown density ranked highest, number of terminals intermediate, and branch angle most acute among the 5 clusters (figures 5, 8). Survival of these seed sources was excellent at all of the sites. Height growth was intermediate at most sites. (figure 7).

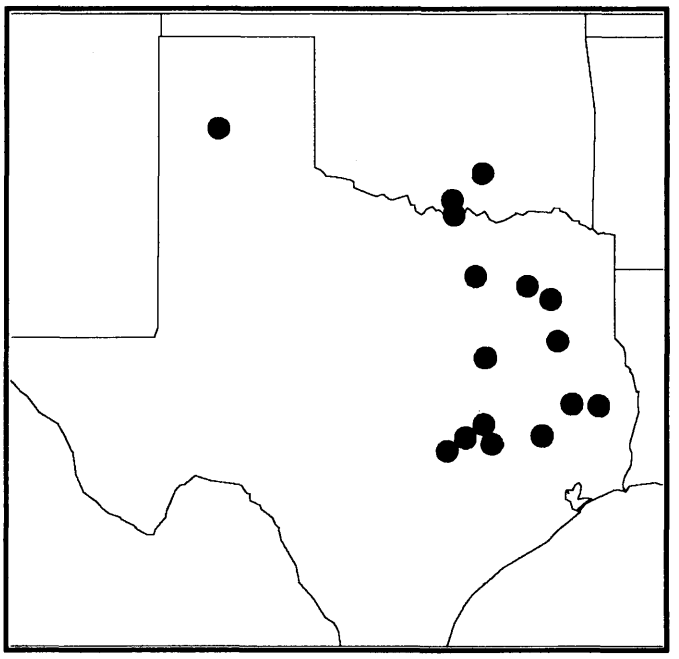

Figure 12. *Juniperus* seed sources in cluster #4 (● = *J. virginiana*).

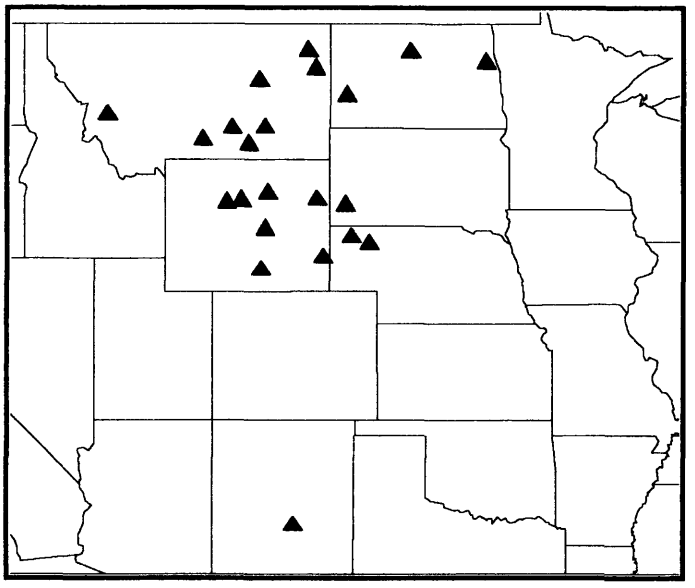

Figure 13. *Juniperus* seed sources in cluster #5 (▲ = *J. scopulorum*).

Averaged over 6 test sites, seed sources from cluster #2 ranked best in survival, height, and crown width. Cluster #2 seed sources tied for second in crown density. Cluster #4 seed sources ranked lowest in these same traits.

Based on performance at each test site, cluster #2 seed sources performed best. Cluster #4 seed sources survived the poorest at test sites in North Dakota, Nebraska, and Kansas; however, their survival improved to second poorest in South Dakota. Average heights of cluster #4 seed sources were shortest at all sites except Mandan, ND.

Genotype by environment interaction was evident in the survival and height of seed sources in clusters #3 and #5 (figs 6, 7). Cluster #3 seed sources survived poorly in the northern plains and Kansas, but well in Nebraska. Height growth of Cluster #3 seed sources was moderate in Nebraska, but poor in North Dakota and Kansas.

The frequency of seed sources classified within each cluster that occurred within cluster #2, which was the best cluster, are shown in table 3. Of all the seed zones in cluster #2, about 89% were classified as belonging to cluster #2. About 5% of the seed sources from the seed zones in cluster #2 were classified as belonging to cluster #1. Only 4% of the seed sources from the seed zones in cluster #2 were classified as belonging to cluster #4. Less than 1% of the seed sources from the seed zones in cluster #2 were classified as belonging to cluster #3. None of the seed sources from the seed zones in cluster #2 were classified as belonging to cluster #5. The high probability that a seed source in cluster #2 belongs to the highest performing cluster indicates the practical utility of choosing seed sources from the cluster #2 territory.

Provenance Transfer Models

Survival was significantly related to latitude at all test sites except Bridger, MT (table 4). Seed sources from up to 4° latitude south of the test sites survived best in the northern Great Plains (table 5, figures 14-16). In the central Great Plains and Missouri, seed sources from the same latitude, to 4 ° north of the test sites survived best (figures 17–21). Longitude was weakly related to survival among seed sources tested in Montana, South Dakota and Nebraska test sites where seed sources from the same latitude as the test sites survived best (table 5, figures 16–18). Elevation of the seed source was very weakly related to survival at Bridger, MT (3,656 ft), Mandan, ND (1,740 ft), Brookings, SD (1,650 ft) and Sacville, MO (1,300 ft). Seed sources from the same elevation as the test site survived best at these sites (table 5).

The influence of latitude on height of the seed sources was similar to its effect on survival, although the distance from the test site to the origin of the best seed source was often greater than for survival (tables 5, 6). At some northern test sites, such as Mandan, heights peaked for seed sources about 4 ° latitude south of the test site (table 5, figure 15). In South Dakota and Nebraska, seed sources from the same latitude as the test sites grew tallest (figures 16-18). At Colby, KS, heights peaked for seed sources about 4 ° latitude north of the test site (figure 19). In Missouri, seed sources from 1 degree latitude north of the test sites grew tallest (table 5). In Montana, seed sources from the farthest latitude north or south of the test site grew tallest (figure 20). Longitude of the seed source was related to the heights of the seed sources at all test sites except Bridger, MT and Sacville, MO (table 5). At several sites, seed sources from 1 to 6 ° longitude east of the test sites were tallest. At Mandan, ND and Plattsmouth, NE, seed sources from the same longitude as the test sites were tallest. Elevation of the seed source had a minor effect on height at South Dakota, Missouri, and Montana sites (table 6). At these sites, seed sources from the same eleva-

Table 3. Frequency of seed sources classified within each cluster that occurred within cluster #2.

			Cumulative	
Cluster No.	**No.**	**%**	**No.**	**%**
2	66	89.2	66	89.2
1	4	5.4	70	94.6
4	3	4.0	73	98.6
3	1	0.7	74	100.0
5	0	0	74	100.0

Table 4. Provenance transfer model relating survival to source location relative to plantation location.

				Regression coefficients[a]						
	Site	**R**	**SE[b]**	**Constant**	**△ Lat.**	**△ Lat.**	**△ Long.**	**△ Long.**	**△ Elev.**	**△ Elev.**
ND	Towner	0.68	14.9	81.3	–6.11	–0.72	—	—	—	—
ND	Mandan	0.77	11.5	88.0	–5.79	–0.87	—	—	-2.5×10^{-3}	2.5×10^{-5}
SD	Brookings	0.74	14.1	77.4	–6.32	–1.19	8.02	–0.35	–0.02	—
NE	Plattsmouth	0.54	6.4	100.6	1.08	–0.15	—	–0.14	—	—
NE	Hastings	0.24	4.3	98.9	0.55	–0.09	—	–0.04	—	—
KS	Colby	0.52	10.7	84.9	3.40	–0.46	—	—	—	—
MO	Sacville	0.75	13.2	92.1	3.25	–0.88	—	—	—	-5.4×10^{-6}
MT	Bridger	0.56	1.4	100.5	—	—	—	—	1.1×10^{-3}	-7.3×10^{-7}

[a] Differences between sources and plantations in latitude (negative values represent sources south of plantations); in longitude (negative values represent sources east of plantations); in elevation (negative values represent sources lower than plantations). Units of latitude and longitude in degrees; elevation in 1000 feet.

[b] Standard error of estimate ($p < 0.01$).

tion as the test site grew slightly taller than seed sources from higher or lower elevations (table 5).

After adjusting the constant for the 10-year mean, prediction of 10-year values by the 5-year models did not indicate bias in the 5-year models (table 7). Only Towner, ND provided any indication of possible bias, but it was not significant ($p = 0.87$).

Correlation

Among Traits

Correlation analyses of seed-source means at each test site revealed significant correlations among many traits (tables 8–10). Cedar apple rust was more highly correlated with seed sources from southern latitudes at all sites except Mandan, ND. Trees from easterly longitudes had more rust at the Missouri site, but the effect was non-significant elsewhere. More rust occurred on Rocky Mountain juniper at Mandan, ND, but it occurred more on eastern redcedar at Nebraska and South Dakota sites. Rust was more prevalent on taller trees at Missouri, Nebraska, and South Dakota, but not at Mandan, ND. Better surviving trees had more rust at Missouri and Nebraska, but the effect was non-significant at North Dakota and South Dakota.

Cedar apple rust and Cercospora blight were negatively correlated at the Nebraska sites and were non-significant

Table 5. Location of best seed sources for each test site.

	Survival			Height		
Location	**Lat.[a]**	**Long.[b]**	**Elev.[c]**	**Lat.[a]**	**Long.[b]**	**Elev.[c]**
Bridger	~[d]	=[e]	=	4°N, 6° S	~	=
Towner	4° S	~	~	=	4° E	~
Mandan	4° S	~	=	4° S	=	~
Brookings	=	=	=	=	1° E	=
Plattsmouth	=	=	~	=	=	~
Hastings	4° N	=	~	=	4° E	~
Colby	4° N	~	~	4° N	6° E	~
Sacville	2° N	~	=	1° N	~	=

[a] Degrees of latitude from the test site to the origin of best seed sources.

[b] Degrees of longitude from the test site to the origin of best seed sources.

[c] Difference in elevation of seed sources in relation to test site.

[d] Minimal influence.

[e] Equal to that of the test site.

Table 6. Provenance transfer model relating height to source location relative to plantation location.

				Regression coefficients[a]						
	Site	**R**	**SE[b]**	**Constant**	**Lat.**	**Lat.**	**Long.**	**Long.**	**Elev.**	**Elev.**
ND	Towner	0.68	14.9	81.3	–6.11	–0.72	—	—	—	—
ND	Towner	0.69	21.2	194.8	–0.65	–3.84	–0.39	—	—	—
ND	Mandan	0.77	27.3	295.0	–16.12	–2.18	—	–0.71	–0.01	—
SD	Brookings	0.56	36.1	272.2	—	–1.04	7.59	–1.23	—	—
NE	Plattsmouth	0.79	37.5	442.4	—	–2.24	—	–0.55	–0.03	—
NE	Hastings	0.81	27.6	360.0	3.01	–1.89	—	–0.85	–0.02	—
KS	Colby	0.78	21.4	295.6	11.18	–1.86	—	–0.59	—	–0. 02
MO	Sacville	0.84	29.5	344.1	—	–2.48	—	—	—	-1.1×10^{-5}
MT	Bridger	0.39	17.3	215.9	—	3.46	—	—	-6.4×10^{-3}	—

[a] Differences between sources and plantations in latitude (negative values represent sources south of plantations); in longitude (negative values represent sources east of plantations); in elevation (negative values represent sources lower than plantations). Units of latitude and longitude in degrees; elevation in 1000 feet.

[b] Standard error of estimate ($p < 0.01$).

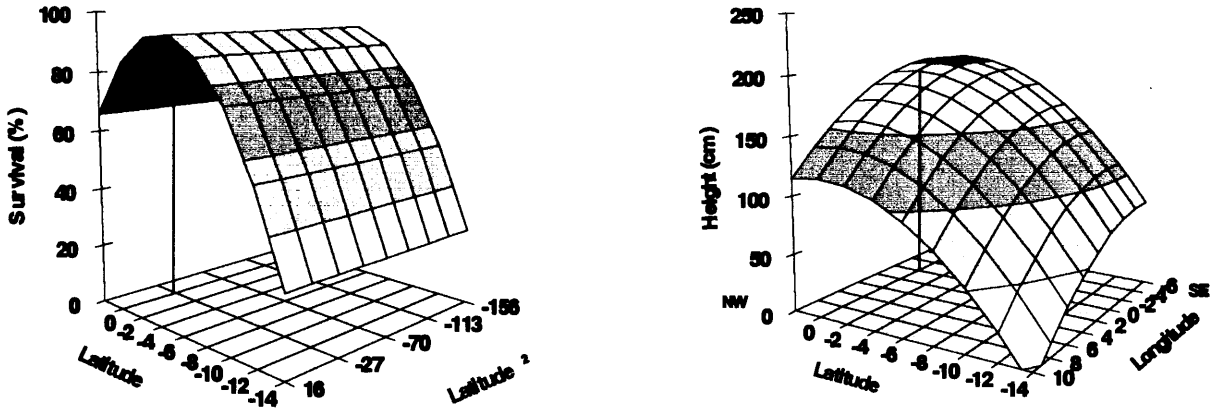

Figure 14. Provenance transfer model for survival and height at Towner, ND. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

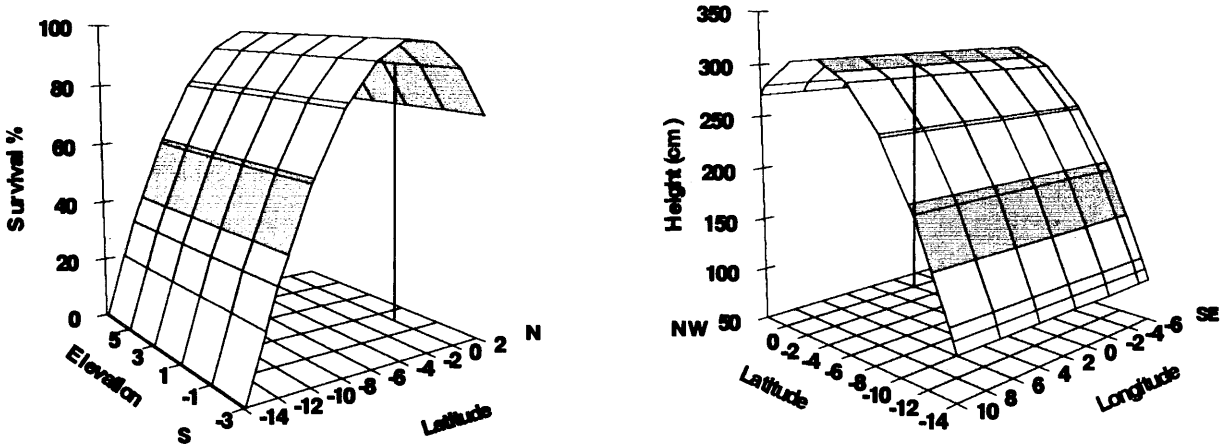

Figure 15. Provenance transfer model for survival and height at Mandan, ND. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

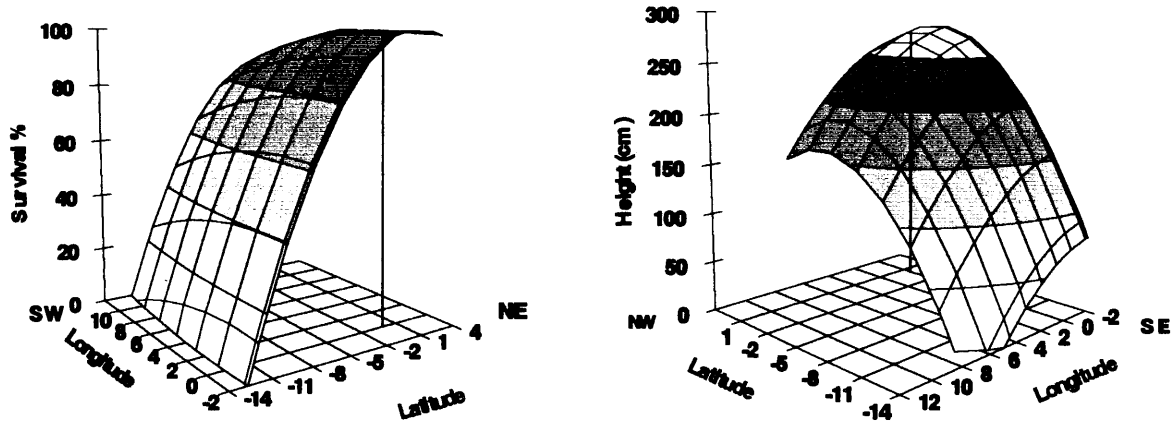

Figure 16. Provenance transfer model for survival and height at Brookings, SD. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

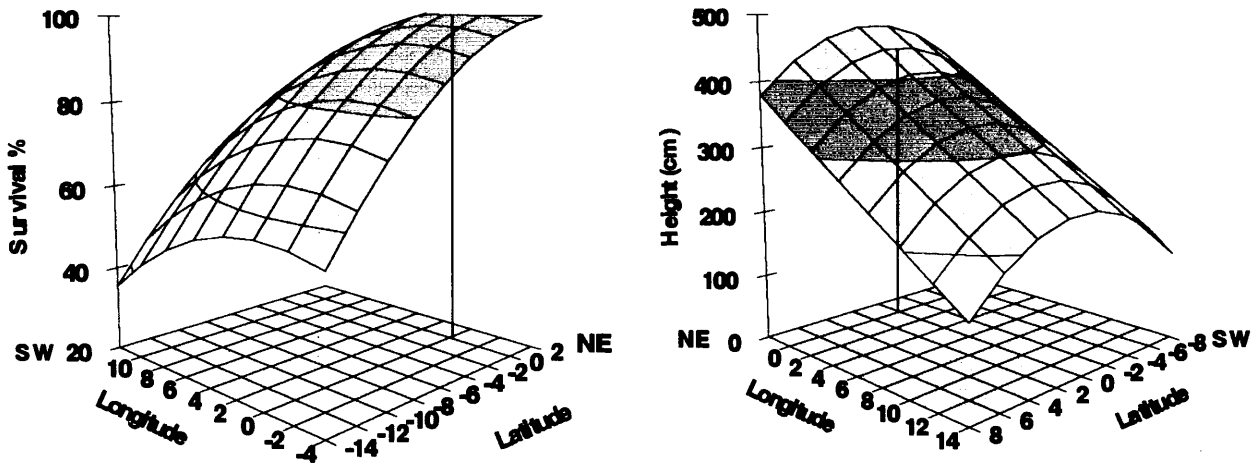

Figure 17. Provenance transfer model for survival and height at Plattsmouth, NE. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

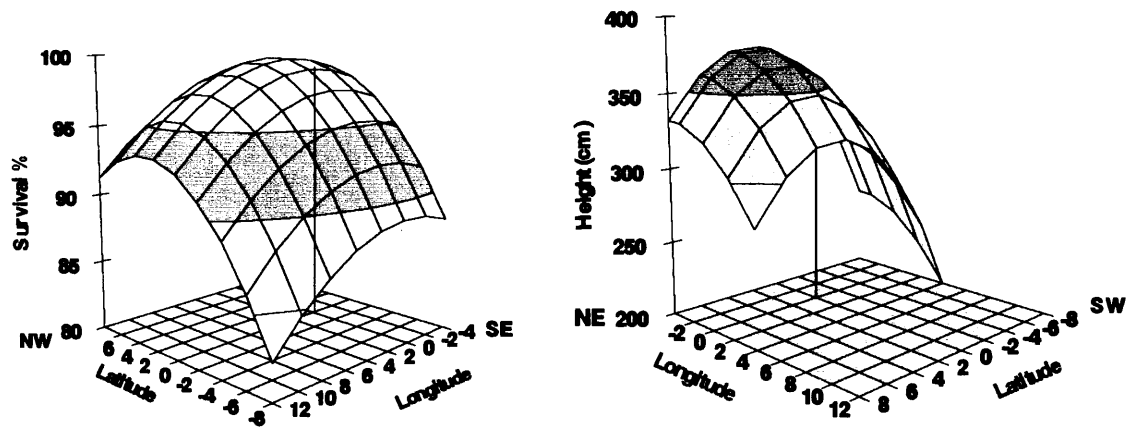

Figure 18. Provenance transfer model for survival and height at Hastings, NE. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

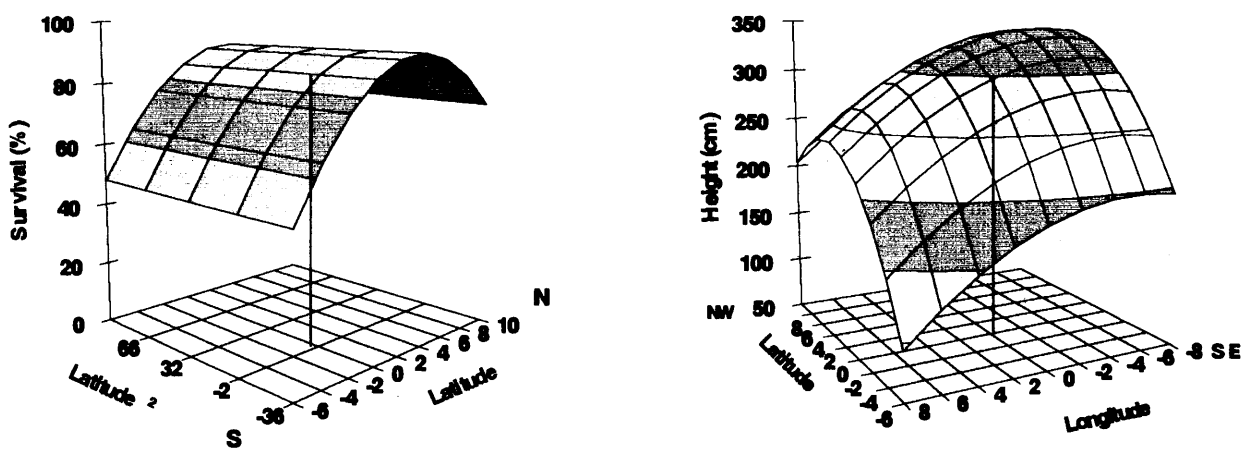

Figure 19. Provenance transfer model for survival and height at Colby, KS. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and longitude.

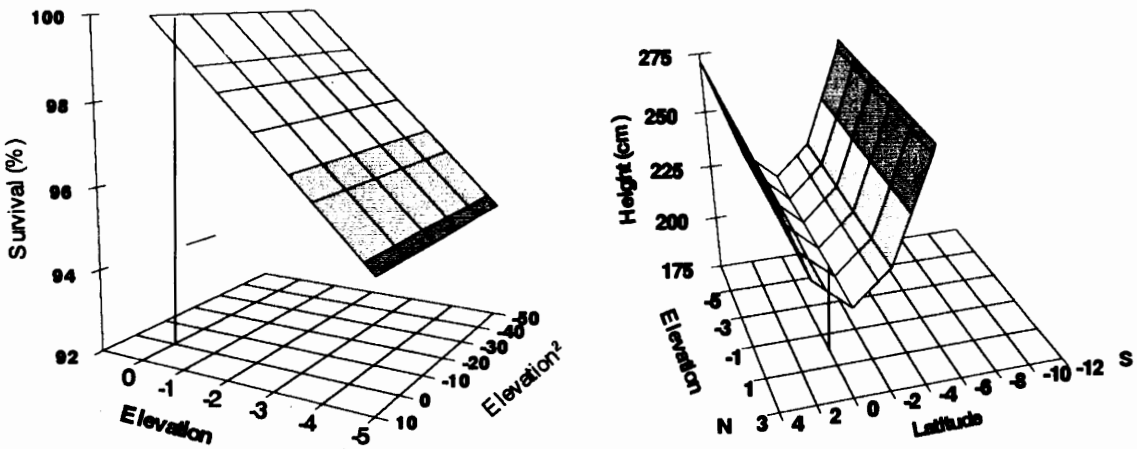

Figure 20. Provenance transfer model for survival and height at Bridger, MT. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and elevation.

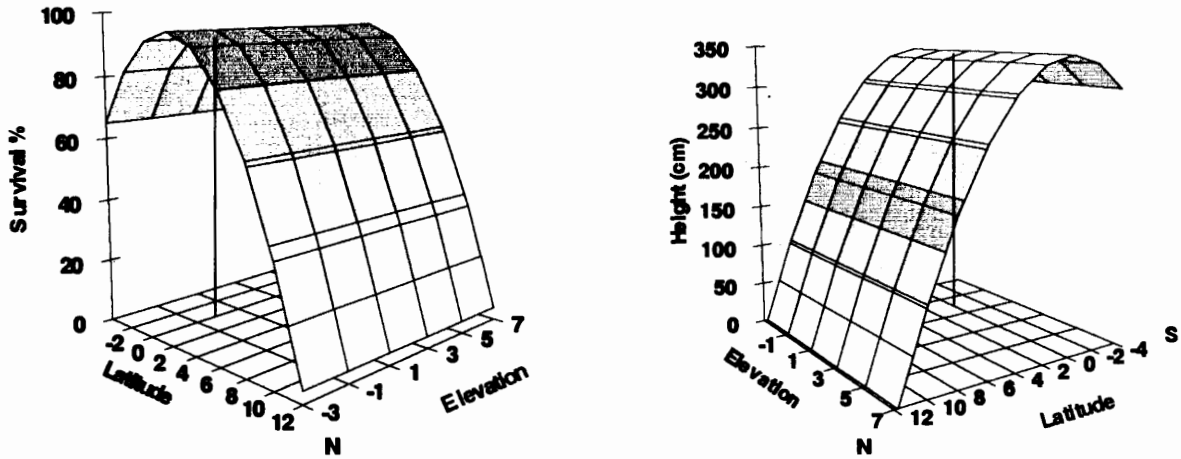

Figure 21. Provenance transfer model for survival and height at Sacville, MO. The vertical line at the origin represents the test site location. See table 4a for definitions of latitude and elevation.

Table 7. Comparison of regression models.

	5-year model			10-year model		
Site	**x** [a]	**p** [b]	**S. E.** [c]	**x** [a]	**p** [b]	**S. E.** [c]
Towner, ND	–0.420	0.871	23.76	0.001	1.000	20.71
Mandan, ND	–0.001	0.999	35.98	0.001	0.999	26.46
Brookings, SD	0.001	1.000	65.04	–0.001	1.000	35.22
Plattsmouth, NE	0.001	0.999	60.66	–0.001	0.999	36.59
Hastings, NE	0.001	1.000	42.37	0.001	0.999	26.76
Colby, KS	0.001	0.999	25.75	–0.001	0.999	20.77

[a] Mean residual.

[b] Probability there was no bias in applying regression model to 10-year data.

[c] Standard error of estimate.

elsewhere. Kabatina and Cercospora were positively correlated at the Nebraska sites, but negatively correlated at the Missouri site. More Cercospora blight occurred on shorter trees at the Nebraska sites, but the effect was non-significant at the Missouri and South Dakota sites.

Kabitina blight and cedar apple rust were negatively correlated at the Missouri site. Kabitina blight was more prevalent on better surviving trees at the Nebraska sites, but at the Missouri site the effect was non-significant. Shorter trees had less Kabitina blight in Nebraska. More Kabitina blight occurred on Rocky Mountain juniper in Nebraska, but the correlation in Missouri was non-significant.

Bagworm, recorded at the Missouri test site only, was positively correlated with cedar apple rust, survival, and height. Bagworm was more prevalent on eastern redcedar than on Rocky Mountain juniper.

Age/Age

Survival and height at age 10 was significantly correlated with survival and height at age 5 (table 11). Correlation of 5-year height with 10-year height was particularly high (0.96).

Table 8. Correlation of diseases and bagworm with selected variables at each test site.[a]

Trait 1	Trait 2	MO	ND2	NE1	NE2	SD
SURV	RUST	0.74	NS	0.32	0.17	NS
HT	RUST	0.75	NS	0.62	0.62	0.44
CER	RUST	NS	—	–0.4	–0.43	NS
KAB	RUST	0.33	—	NS	NS	—
SURV	CER	NS	—	NS	NS	—
HT	CER	NS	—	–0.5	–0.54	NS
KAB	CER	–0.37	—	0.74	0.68	—
SURV	KAB	NS	—	0.21	0.2	—
HT	KAB	NS	—	–0.2	–0.24	—
SURV	BAG	0.5	—	—	—	—
HT	BAG	0.58	—	—	—	—
RUST	BAG	0.72	—	—	—	—
CERC	BAG	NS	—	—	—	—

[a] All values are significant (p<0.01).

Table 9. Correlation of species with selected variables at each test site.[a, b]

Trait 1	Trait 2	KS	MO	MT	ND1	ND2	NE1	NE2	SD
SURV	SP	NS	–0.85	0.36	NS	NS	NS	NS	0.23
HT	SP	NS	–0.78	NS	NS	NS	–0.6	–0.55	NS
RUST	SP	—	–0.73	—	—	0.47	–0.62	–0.56	–0.72
CERC	SP	—	0.32	—	—	—	0.84	0.8	NS
KAB	SP	—	NS	—	—	—	0.51	0.55	—
BAG	SP	—	–0.43	—	—	—	—	—	—

[a] All values are significant (p<0.01).

[b] Species were coded: *J. virginiana* = 1; *J. scopulorum* = 2.

Table 10. Correlation of latitude and longitude with selected variables at each test site.[a]

Trait 1	Trait 2	KS	MO	MT	ND1	ND2	NE1	NE2	SD
SURV	LAT	0.60	–0.52	0.62	0.52	0.59	NS	0.41	0.56
HT	LAT	0.24	–0.53	0.44	0.33	0.33	–0.32	NS	0.28
RUST	LAT	—	–0.47	—	—	0.30	–0.31	–0.35	–0.27
SURV	LONG	NS	–0.65	NS	NS	NS	NS	NS	NS
HT	LONG	NS	–0.62	NS	NS	NS	NS	NS	NS
RUST	LONG	—	–0.50	—	—	NS	NS	NS	NS

[a] All values are significant (p<0.01).

Table 11. Correlation among survival and height measured at 5 and 10 years.[a]

	Variables		
	Surv-10	**Ht-5**	**Ht-10**
Surv-5	0.68	0.39	0.37
Surv-10		0.57	0.54
Ht-5			0.96

[a] All values are significant ($p<0.001$).

Discussion and Interpretation

The wide geographic distribution of seed sources sampled in this study and the inclusion of Rocky Mountain juniper and eastern redcedar, resulted in significant differences among the seed sources for most of the traits measured or recorded. Differences between the species are not unexpected for many traits, particularly crown characteristics and susceptibility to pests. When the performance of the seed sources was averaged over all 6 test sites and clusters of those performing in a similar manner were derived, most of the resulting clusters were composed of seed sources of the same species and geographic region. However, seed sources in cluster #1 included both species and were from opposite ends of the Great Plains. Mean survival, height, and crown characteristics of cluster #1 seed sources were intermediate in rank among the 5 clusters. This may be evidence of hybridization and introgression between the 2 species in the areas where these seed sources originated. Schaefer (1995), however, suggests that results from the South Dakota test site and molecular research (Stephen Ernst, Univ. Nebr., pers. Comm.) indicate that such introgressive hybridization is highly unlikely.

Of the clusters comprised primarily of eastern redcedar, seed sources in cluster #2 performed best in survival, height, and crown width. Seed sources in cluster #5 were exclusively Rocky Mountain juniper. These seed sources survived well and had compact, conical crowns.

The strong correlation of 5-year height with 10-year height and the univariate analysis reveals that the 5-year model could predict the 10-year height with little probability of bias. This suggests that seed sources that perform well at age 10 can be successfully identified at age 5, thus reducing the time necessary to choose the best seed source for a particular planting site.

The results of this study provide a guide for selecting seed sources for seedlings to plant at specific sites in the Great Plains. In North Dakota, seed sources from 4 ° latitude south (1 ° = 70 miles) of the planting site survived the best and grew the tallest. Seed sources from the same latitude and longitude as the test site survived best and from the same latitude and 1 ° longitude east, grew the tallest in South Dakota. In Nebraska, seed sources from the same to 4 ° latitude north of the planting site survived best and those from the same latitude and from the same to 4 ° east of the Hastings planting site, grew the tallest. Seed sources from 4 ° north of the Kansas site survived best, and those from 4 ° latitude north and 6 ° longitude east grew the tallest. In Missouri, seed sources from 2 ° north survived best and those from 1 ° latitude north grew the tallest. Seed sources from the same longitude and elevation as the Bridger test site survived best, while those from 4 ° latitude north or 6 ° latitude south of the test site grew the tallest. The unusual effect of latitude of the seed source on height at Bridger, MT was unexpected and difficult to explain, because the results at other test sites in the northern Plains generally show that seed sources from north of the test site grow more slowly.

The use of a seed source from within 70 miles of the planting site would be a conservative approach to seed collection. In most cases, this approach would produce planting stock that would survive well and grow to an acceptable height. However, using the above stated guidelines could result in significant increases in growth rate while maintaining adequate survival.

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Literature Cited

Adams, R.P. 1983. Intraspecific terpenoid variation in *Juniperus scopulorum*: evidence for Pleistocene refugia and recolonization in western North America. Taxon. 32: 30–46.

Comer, C.; Adams, R.P.; Van Haverbeke, D.F. 1982. Intra- and interspecific variation of *Juniperus virginiana* and *J. scopulorum* seedlings based on volatile oil composition. Biochemical Systematics and Ecology. 10: 179–306.

Cunningham, R.A. 1975. Provisional tree and shrub seed zones for the Great Plains. Res. Pap. RM-150. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.

Fassett, N.C. 1944. *Juniperus virginiana, J. horizontalis* and *J. scopulorum* – II. Hybrid swarms of *J. virginiana* and *J. scopulorum*. Bull Torrey Bot. Club. 71: 475-483.

Flake, R.H.; Urbatsch, L.; Turner, B.L. 1978. Chemical documentation of allopatric introgression in *Juniperus*. Systematic Botany. 3: 129–144.

Hall, M.T. 1952. A hybrid swarm in *Juniperus*. Evolution. 6: 347-366.

Hochburg, Y.; Tamhane, A.C. 1987. Multiple Comparison Procedures. New York: John Wiley and Sons. 450 p.

Miller, R.G., Jr. 1981. Simultaneous Statistical Inference, 2nd ed. New York: Springer-Verlag. 299p.

Schaefer, P. 1995. Ten-year results of an eastern redcedar and Rocky Mountain juniper provenance test in eastern South Dakota. Northern J. Applied Forestry 12 (1): 30 – 35.

Schurtz, R.H. 1971. A taxonomic analysis of a triparental hybrid swarm in *Juniperus*. Lincoln, NE: University of Nebraska. 90 p. Ph.D. dissertation.

Siegel, S.; Castellan, N.J., Jr. 1988. Nonparametric Statistics for the Behavioral Sciences, 2nd ed. New York: McGraw-Hill. 399 p.

Van Haverbeke, D.F. 1968. A population analysis of *Juniperus* in the Missouri River Basin. New Series 38. Lincoln, NE: University of Nebraska Studies. 82 p.

Van Haverbeke, D.F.; R.M. King. 1990. Genetic variation in Great Plains *Juniperus*. Res. Pap. RM-292. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 8 p.

von Rudloff, E. 1975. Volatile oil analysis in chemostytematic studies of North American conifers. Biochemical Systematics and Ecology. 1: 131–167.

Zhang, J.W.; Klopfenstein, N.B.; Peterson, G.W. 1997. Genetic variation in disease resistance of *Juniperus virginiana* and *J. scopulorum* grown in eastern Nebraska. Silvae Genetica 46 (1): 11–16.

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