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Genetic Variation in Ponderosa Pine: A 15-Year Test of Provenances in the Great Plains

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Abstract

Survival was highest and height growth greatest in ponderosa pine provenances from northcentral Nebraska, southwest South Dakota, and the High Plains region. Genotype × environment interaction was minimal in central and northern Great Plains plantations. Age/age correlations indicate provenances expressing superior height growth can be identified after 5 or 10 years.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Management Implications

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) has been planted extensively in windbreaks, wildlife, esthetic, and environmental plantings throughout the northern and central Great Plains, and to a lesser extent in the southern Great Plains, for more than one hundred years. The initial survival of ponderosa pine, however, is often erratic and its height growth is variable (Read 1958). One reason for the occasional failure of ponderosa pine in the Great Plains has been the use of poorly adapted seed sources.

Identification of ponderosa pine seed sources that combine high survivability and height growth potential is of great importance for planting in the Great Plains and adjacent regions. This study found that seed sources from northcentral Nebraska, southwest South Dakota, and the High Plains region survived best and grew well throughout the Great Plains. Utilization of these seed sources in planting programs will improve the genetic quality and adaptability of the material planted; thus, enhancing the establishment and survival of this species within the Great Plains.

Introduction

Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.), also known as interior ponderosa pine, is widely distributed throughout the Rocky Mountains. In the north it occurs east of the Continental Divide in central Montana, and extends eastward into southwest North Dakota, then southward into Wyoming, west and southcentral South Dakota, and west and northcentral Nebraska (Little 1971, 1979). South of Wyoming the species occurs on both sides of the Continental Divide in Colorado and New Mexico, including northwest Oklahoma and the Trans-Pecos of Texas, and extends west into Utah, Nevada, and Arizona. The name *scopulorum* is sometimes extended south of the region to which it initially applied (i.e., to stands in New Mexico, Arizona, and west Texas). However, the ponderosa pine in these southern stands is distinctly different from those of the northern range *scopulorum*, especially in needle length (Read 1980) and monoterpene characteristics (Smith 1977).

Many of the climatic and edaphic characteristics within the range of var. *scopulorum* (i.e., temperature extremes, high evaporation stress, limited precipitation, high winds, variable soils, etc.) are similar to those of the Great Plains.

Nursery and 10-year performances of 79 seed sources of ponderosa pine, collected from throughout this range, were reported previously (Read 1980, 1983). Analysis of the nursery data by ISODATA cluster analysis techniques grouped these seed sources into nine geographic clusters of similar performance in seven plantations analyzed. Two of these clusters were located west of the Continental Divide, and contained provenances described as var. *ponderosa*; seven were essentially east of the Continental Divide, containing provenances described as var. *scopulorum*.

The 10-year analysis, employing similar clustering techniques, grouped the same seed sources into six clusters, five of which contained sources described as var. *scopulorum*. While the clusters identified in the 10-year and in this 15-year analysis, were not the same as those delineated in the nursery analysis, there were close similarities.

The six, 10-year analysis clusters were named geographically the Northwest, Northern High Plains, Northcentral Nebraska, Black Hills-Foothills, Central Rocky Mountain, and Southern clusters. The Northcentral Nebraska cluster, consisting of three sources, produced trees which grew taller than the average of trees in all other sources in all plantations.

Fifteen-year survival and height growth are reported here. The objectives of this evaluation were to: (1) identify origins of superior performing seed sources; (2) determine the consistency of their performance across the range of plantations, and within regional groupings of plantations; and, (3) determine how early reliable patterns in height growth are expressed.

Materials and Methods

Cone collection, nursery and plantation establishment, and plantation maintenance procedures were previously documented (Read 1980, 1983). Seeds were collected from 1962 through 1964, from 10 to 15 trees in each of 79 natural stands throughout the ponderosa pine (var. *scopulorum*) range, east of the Continental Divide; and populations in the ponderosa pine (var. *ponderosa*) range, west of the Continental Divide. Seeds from individual trees sampled within a population were bulked into provenance seedlots, sown, and grown from 1965 through 1968 at the USDA Forest Service Bessey Nursery near Halsey, Nebr. and at the North Dakota State Nursery near Towner, N. D.

Seedlings were distributed from 1968 through 1970 to cooperators for the establishment of 28 plantations, mostly in the Great Plains. Survival and height at 16 of the plantations are reported here (table 1). Low survival or no data precluded valid analysis of the other plantations. The intended field design was to establish the 79 provenances in randomized complete blocks at each plantation, with 15 replications of 4-tree-linear

Table 1.—Plantation locations and establishment data for sixteen plantings of ponderosa pine provenances.

	State or province	Plantation location	North Lat.	West Long.	Elevation	Seed provenances	Trees per plot	Replications per plantation	Trees per provenance
			(deg.)	(deg.)	(feet)	(no.)	(no.)	(no.)	(no.)
	Saskatchewan	Indian Head	50.4	103.6	1,800	70	4	15	60
△	N. Dak.	Towner	48.4	100.4	1,500	79	4	15	60
	S. Dak.	Watertown	44.9	97.1	1,740	73	4	8	32
	Minn. (1)	Grand Rapids	47.2	93.5	1,300	70	4	3	12
	Minn. (2)	Morris	45.6	95.9	1,100	72	4	6	24
	Minn. (3)	Lamberton	44.2	95.2	1,000	72	4	9	36
△	Mich. (1)	Kellogg	42.4	85.4	800	75	6	5	30
	Mich. (2)	Russ	42.0	86.0	700	75	6	5	30
△	Nebr. (1)	Alliance	42.1	102.9	4,000	79	4	15	60
△	Nebr. (2)	Halsey	41.9	100.4	2,900	79	4	15	60
	Nebr. (3a)	Hastings	40.6	98.3	1,900	79	25	4	100
△	Nebr. (3b)	Hastings	40.6	98.3	1,900	79	4	15	60
	Nebr. (4)	Plattsmouth	41.0	95.9	1,100	50	10	6	60
△	Kans.	Milford	39.0	96.9	1,000	77	4	15	60
	Okla.	Norman	35.1	97.5	1,100	40	4	15	60
△	Mo.	Columbia	38.9	92.2	700	78	4	10	40

△ Denotes plantations used in the ISODATA cluster/discriminant analysis.

plots. There were variations in the experimental design among plantations, depending upon local conditions (table 1).

Analyses of variance (alpha = 0.05) and unequal sample size multiple range tests were applied to evaluate tree survival and height growth in each plantation. Significant variation was indicated among provenances in each plantation. However, the multiple comparison tests were sufficient to statistically detect only differences between the very best surviving and tallest trees and the very poorest surviving and shortest trees. Provenances with intermediate expression of these trait values were grouped within a multi-layered series of overlapping designations.

Toward a more interpretable analysis, provenance, survival, and height growth means were partitioned into groups of provenances based on similarity across the range of plantations using ISODATA cluster analysis (Ball and Hall 1965, 1966) and discriminant analysis (Brown and Tinsley 1983). Separate analyses were run for survival and height, producing two groups of clusters.

Because performance in each plantation was independent of all other plantations, the average survival and height growth of each provenance in the different plantations were used as independent traits. Cluster analysis segregates provenances into groups (clusters) whose independent variables perform consistently and similarly in all plantations. Discriminant analysis assesses the degree of separation among the clusters of provenances, identifies provenances possibly misclassified by the cluster analysis, and indicates the relative importance of each plantation's contribution to the clustering procedure.

Missing data, resulting from provenances intentionally omitted from some plantations, lack of seedlings for complete stocking in all plantations (Read 1983), and poor survival in some plantations, restricted analyses to seven plantations: Towner, ND; Kellogg Forest, MI–1; Alliance, NE–1; Halsey, NE–2; Hastings, NE–3b; Milford, KS; and Columbia, MO (designated in tables 1 and 2). The small numbers of missing data in these plantations were computed by a randomized block technique (John 1971).

Genotype × environment interaction was determined by Spearman's rank correlation coefficients (Snedecor 1961) for provenances within regions (northern, eastern, central, and southern) and compared with similarly computed coefficients between provenance means for the four regions. If there is a G × E interaction, the correlation coefficients should be much greater within regional groups compared with the correlations among the regional group means.

Genetic age/age correlations were computed for a matrix of 2- and 3-year nursery means for each seed source, and the 5-, 10-, and 15-year regional source means.

Results and Discussion

Survival

Five clusters provided good definition for survival, identifying groups of provenances surviving similarly over the seven plantations (fig. 1). These were identified geographically as the Northwest, Northern High Plains, High Plains-Black Hills-Foothills, Central Rocky Mountain-Foothills, and Southern clusters. These five clusters of provenances were used as groups for the discriminant analysis in which plantations were the independent variables discriminating among groups of similar provenances. This analysis was 95% in

Table 2.—Mean survival (%), height (ft), and percent of plantation mean height of 15-year-old ponderosa pine provenance trees by plantation and geographic clusters.[1]

Cluster	No. of Proven.		Northern: Indian Head Sask	Northern: Towner ND	Northern: Watertown SD	Eastern Plantations: Gr. Rapids MN-1	Eastern Plantations: Morris MN-2	Eastern Plantations: Lambarton MN-3	Eastern Plantations: Kellogg MI-1	Eastern Plantations: Russ MI-2	Central: Alliance NE-1	Central: Halsay NE-2	Central: Hastings NE-3a	Central: Hastings NE-3b	Central: Plattsmouth NE-4	Southern: Milford KS	Southern: Norman OK	Southern: Columbia MO	Cluster Means
Northwest	7	% Surv.	0.0	10	38	12	34	30	90	71	29	25	37	56	96	53	66	86	49
		$\bar{x}$ Ht.	0.0	2.8	8.7	9.8	10.0	8.3	22.6	23.0	7.4	5.2	10.1	9.8	21.9	7.3	13.0	17.1	11.1
		% Plt. $\bar{x}$	0.0	66	73	95	78	68	114	122	71	85	83	83	101	84	95	105	83
Northern High Plains	22	% Surv.	—	53	92	61	62	59	83	78	80	44	96	98	99	89	85	92	78
		$\bar{x}$ Ht.	12.4	5.0	13.9	12.6	16.0	13.1	20.5	20.3	11.0	7.3	13.4	13.1	22.6	9.9	14.4	17.0	13.9
		% Plt. $\bar{x}$	106	117	118	111	109	106	103	107	105	118	111	110	105	114	105	105	109
North-Central Nebraska	3	% Surv.	—	63	95	58	75	65	65	78	83	39	97	100	100	88	91	96	79
		$\bar{x}$ Ht.	14.5	7.3	15.8	12.8	15.2	14.1	23.2	22.2	12.1	9.7	16.1	16.9	23.9	14.7	18.6	18.0	13.8
		% Plt. $\bar{x}$	124	170	134	108	119	115	116	117	115	139	133	142	111	170	134	111	129
Central Rocky Mountains	14	% Surv.	—	37	70	47	57	49	89	72	87	37	99	99	98	85	71	84	72
		$\bar{x}$ Ht.	10.0	3.7	10.2	8.8	11.0	11.7	17.8	18.6	9.8	5.0	10.7	10.3	20.8	7.1	11.4	14.1	11.2
		% Plt. $\bar{x}$	85	86	87	85	86	95	90	86	94	84	89	87	97	82	83	87	88
Foothills-Black Hills	25	% Surv.	—	43	75	52	57	53	81	73	85	37	98	99	98	88	81	88	74
		$\bar{x}$ Ht.	11.5	4.2	12.0	10.3	13.0	12.5	20.0	18.3	10.2	6.2	12.2	11.9	21.2	8.4	13.3	16.0	13.4
		% Plt. $\bar{x}$	98	99	102	99	101	101	100	96	102	101	101	101	98	97	97	99	100
Southern	8	% Surv.	0.0	2	18	3	8	15	64	42	73	15	74	85	92	70	77	76	48
		$\bar{x}$ Ht.	0.0	2.0	5.5	8.2	10.1	11.7	18.9	18.4	9.7	4.6	10.8	10.9	20.9	7.7	14.3	17.4	10.6
		% Plt. $\bar{x}$	0.0	47	46	79	79	84	95	97	92	75	89	92	97	89	105	107	80
No. Prov.	79		58	72	72	63	66	69	75	75	79	78	79	79	50	77	40	78	69
Plantation Means:																			
$\bar{x}$ 15-yr. Survival (%)			—	38	74	50	54	50	82	71	78	36	90	94	97	83	80	87	68.4
$\bar{x}$ 15-yr. Height (ft)			11.7	4.3	11.8	10.4	12.8	12.3	19.2	19.0	10.5	6.2	12.1	11.9	21.6	8.7	13.7	16.3	12.2
Cluster basis				△					△		△	△		△		△		△	

[1] = data submitted as plot means only; 0 = planted, none survived; N/A = data not available.
△ = plantation data in ISODATA cluster/discriminant analysis.

agreement with provenance assignment in the cluster analysis, and suggested reassignment of provenances 727, 759, 826, and 844 from the Central Rocky Mountain to the Northern High Plains cluster; all were reassigned to the Northern High Plains cluster (fig. 1). The Northern High Plains cluster had the highest mean survival (88%), followed by the High Plains-Black Hills-Foothills (75%), Central Rocky Mountain (66%), Northwest (49%), and Southern (44%) clusters (fig. 1).

The discriminant analysis revealed that among the seven plantations tested, the Alliance, NE–1 plantation contributed most to survival cluster assignment, accounting for 15% of the additional variation; followed by the Towner, ND (3%) and the Halsey, NE–2 (2%) plantations. Factors attributable to the Alliance, NE–1 plantation in contributing to survival clustering might include its westerly location in closest proximity to the natural distribution of the species and the majority of the provenance origins, and to its mid-latitude location relative to the other plantations (Read 1983). Survival percentages were generally lower in the northern plantations (ND, MN) and generally higher in the eastern and southern plantations (NE–4, MI, KS, OK, MO).

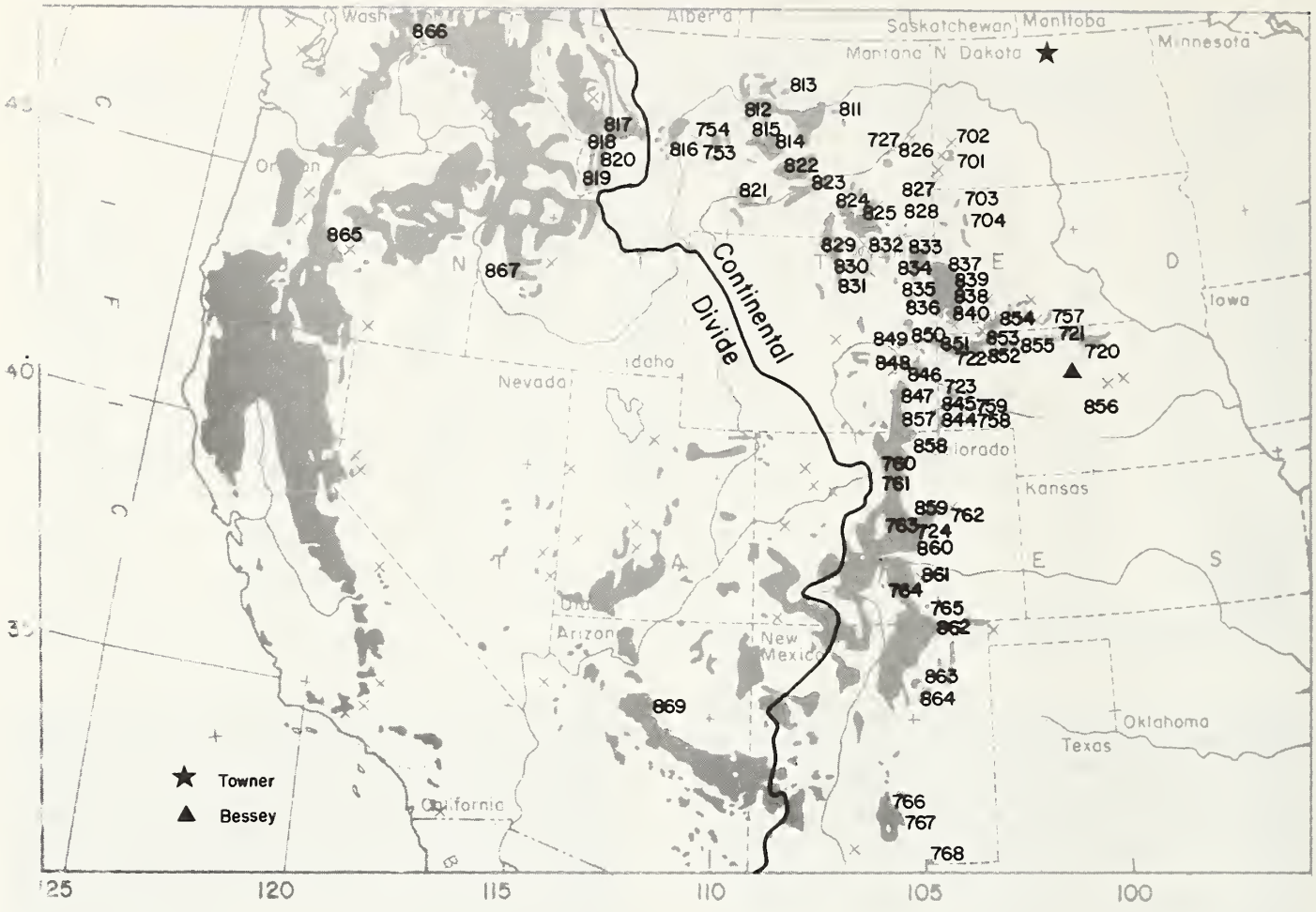
Height

Good definition of the height growth of provenances in the seven plantations was obtained with six clusters (fig. 2). These, the same clusters as those identified in the 10-year analysis, were the Northwest, Northern High Plains, Northcentral Nebraska, Central Rocky Mountain, Foothills-Black Hills, and Southern clusters. Plantations served as the cluster variables, provenances as the cases, and height means for a provenance as the individual observations.

The discriminant analysis was 96% in concurrence with the six cluster delineation; but indicated reassignment of provenances 701, 703, and 724, which were reassigned to their respective clusters (fig. 2). The Northern High Plains and Northcentral Nebraska clusters demonstrated the best height growth over all plantations with mean height values of 13.9 and 13.8 feet, respectively (table 2, fig. 2). These were followed by the Foothills-Black Hills (13.4 feet), Central Rocky Mountain (11.2 feet), Northwest (11.1 feet), and Southern (10.6 feet) clusters. The discriminant analysis revealed that among the seven plantations tested, the Hastings, NE–3b plantation contributed most to cluster assignment, accounting for 16% of the additional variation, followed by the Kellogg, MI–1 (5%), and the Alliance, NE–1 (2%) plantations.

Reasons for the role of the Hastings, NE–3b plantation contributing to height clustering may be similar to those suggested for survival clustering, with the added factor of the near central location of this plantation relative to all other plantations. There, trees tended to be intermediate in height to the generally taller heights in eastern and southern plantations, and the generally shorter heights in the northern and western plantations (table 2). The Kansas plantation, heavily infested with the tip moth insect (*Rhyacionia bushnelli* Busck), is an exception in the southern plantations.

Although the clusters identified in this analysis were the same as in the 10-year analysis, there were some changes in the composition of some clusters. The 15-year Southern height cluster annexed provenances 860, 861, and 862 from the more northerly 10-year Foothills-Black Hills cluster (fig. 2). This change suggests a diminishing degree of adaptation of the southernmost provenances of the Foothills-Black Hills cluster during the past 5 years.



Survival Clusters

Northwest (49%)

817	865
818	866
819	867
820	

Northern High Plains (88%)

703	753	812	825		
704	754	813	826		
720	757	816	837		
722	759	821	838		
723	761	822	844		
727	811	823	850		

High Plains-Black Hills-Foothills-Rocky Mountain (75%)

701	762	827	833	845	853
702	763	828	834	846	854
721	764	829	835	848	855
724	814	830	836	849	856
758	815	831	839	851	858
760	824	832	840	852	

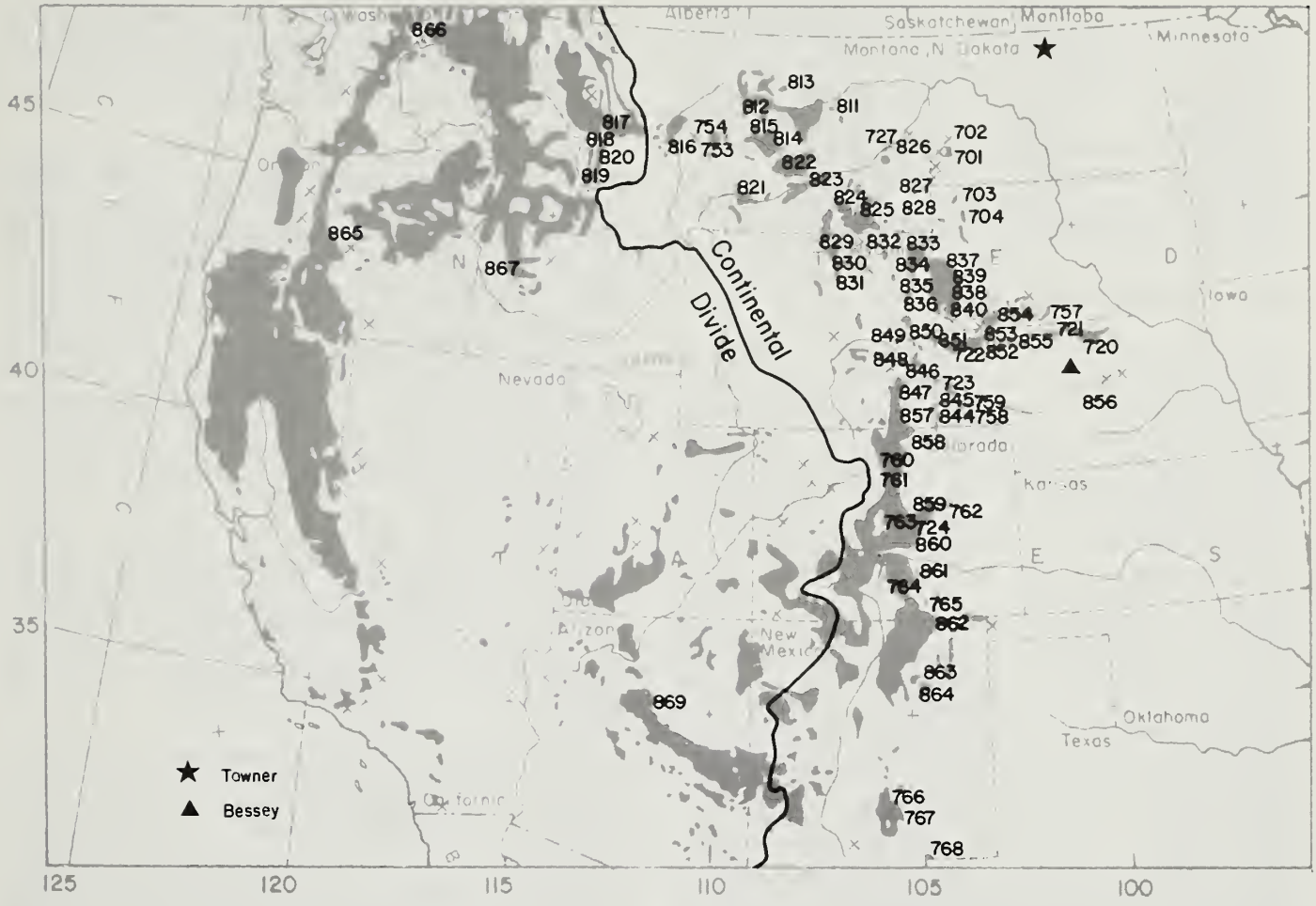
Central Rocky Mountain-Foothills (66%)

765	861
847	862
857	863
859	864
860	

Southern (44%)

766
767
768
869

Figure 1.—Fifteen-year survival ponderosa pine clusters, as determined by cluster/discriminant analysis.



Height Clusters

Northwest (11.1 ft)

817	865
818	866
819	867
820	

Northern High Plains (13.9 ft)

703	821	833
722	822	837
753	823	840
754	824	852
811	825	853
812	827	854
816	828	855
		856

No. Cen. Nebraska (13.8 ft)

720
721
757

Cen. Rocky Mountains (11.2 ft)

724	831
760	844
761	847
762	848
763	849
829	857
830	858

Foothills-Blackhills (13.4 ft)

701	765	836
702	813	838
704	814	839
723	815	845
727	816	846
758	832	850
759	834	851
764	835	859
		863

Southern (10.6 ft)

766
767
768
860
861
862
864
869

Figure 2.—Fifteen-year height ponderosa pine clusters, as determined by cluster/discriminant analysis.

The 15-year Foothills-Black Hills height cluster annexed provenances 701, 704, 727, and 826 from the 10-year Northern High Plains cluster. This suggests a diminishing advantage in height growth of some provenances in the tall-growing Northern High Plains cluster. The Central Rocky Mountain cluster showed no meaningful changes during the past 5 years; and the Northwest and Northcentral Nebraska cluster provenance compositions remained unchanged.

Survival-Height Relationship

Similar patterns of survival and height growth were apparent throughout the sampled area (i.e., provenances and clusters of provenances with highest survival generally produced the tallest trees, and those with poorest survival generally produced the shortest trees). The Northwest survival and height clusters were identical in composition and showed a relatively low across-all-plantations survival of 49% and a relatively low total height of 11.1 feet (table 2, figs. 1 and 2). The combined Southern and Central Rocky Mountain-Foothills survival clusters approximated the Southern height cluster in provenance composition, and showed a relatively low combined average survival percentage of 55 and a total height of 10.6 feet. The remaining clusters were less well defined, although a pattern of increasing survival, excluding the Northwest cluster (49%), was apparent from south to north in the Central Rocky Mountain (66%), High Plains-Black Hills-Foothills (75%), and Northern High Plains (88%) clusters (fig. 1). A similar pattern of increasing height from south to north-northeast was observed (Southern, 10.6 feet; Central Rocky Mountain, 11.2 feet; Foothills-Black Hills, 13.4 feet; Northcentral Nebraska, 13.8 feet; and Northern High Plains, 13.9 feet) (table 2, fig. 2).

The five survival clusters and six height clusters, in addition to being different in number, contained different combinations of provenances in some clusters, complicating provenance cluster survival-height evaluation. Therefore, survival clusters were disassembled and provenance survival percentages by plantation were paired with provenance height means of the same plantation within the six identified height clusters (table 2). Mean survival and height, and percent-of-plantation mean height were calculated for clusters in the 16 plantations (table 2).

Survival of provenances from the Northern High Plains and the Northcentral Nebraska clusters averaged 78%. Survival was above 78% in the South Dakota, Nebraska–1, –3a, –3b, –4; Kansas; Oklahoma; Missouri, and Michigan–1 plantations; and was at or below this mean in the Saskatchewan; North Dakota; South Dakota; Nebraska–2; Minnesota–1, –2, –3; and Michigan–2 plantations (table 2). The 25 provenances in the Foothills-Black Hills cluster showed intermediate survival and height growth between the better performing Northern High Plains and the poorer performing Central Rocky Mountain cluster provenances.

Many provenances in the Northern High Plains cluster survived and grew well, exceeding mean values for survival (68%) in all but five plantations (SD; MN–1, –2, –3; NE–2) and height in all but four plantations (ND; NE–1, –2; KS) (table 2).

The Northern High Plains and the Northcentral Nebraska clusters averaged 13.9 and 13.8 feet in height across-all-plantations respectively; exceeding the overall mean height (12.2 feet) of all plantations by 1.6 feet (table 2). The Northern High Plains provenances exceeded 100% of the plantation mean heights in all plantations, with an overall average of 109%. The Northcentral Nebraska provenances exceeded the plantation mean height percentages in all but one plantation (MI–1) with an average of 129%. However, they did not survive better than many provenances in the Northern High Plains cluster. Only provenance 720 exceeded the plantation mean survival by more than 10% in half or more of the plantations.

The seven provenances of var. *ponderosa* in the Northwest cluster either failed or showed low survival and poor height growth in most of the northern and western Great Plains plantations (SASK; ND; MN; NE–1, –2, –3a, –3b; KS); but survived and grew above the plantation means in plantations east and south of the central-northern Great Plains (NE–4; MI–1, –2; OK; MO) (table 2).

Provenances in the Southern cluster grew well in the Michigan plantations and showed improvement in the Nebraska (except NE–2), Kansas, Missouri, and Oklahoma plantations; but failed or survived poorly in the northern plantations (SASK, ND, SD, MN) (table 2). Overall performances of the Southern provenances, plus some of the southernmost provenances in the Foothills-Black Hills (765, 859, 863) and Central Rocky Mountain clusters (847, 857) were characterized by inconsistent performances in most plantations.

Genotype × Environment Interaction

Genotype × environment interaction is defined as the "failure of entries to maintain the same relative ranks and level of differences when tested in different environments; the tests (entries) are planted at more than one location or under more than one cultural condition" (Snyder 1972).

There was minimal G × E interaction with respect to cluster rankings among the Northcentral Nebraska (#1), Northern High Plains (#3), and Foothills-Black Hills (#5) clusters in plantations located in the central-northern Great Plains (SASK; ND; SD; NE–1, –2, –3a, –3b; KS) and adjacent Minnesota (MN–1, –2, –3) (table 3). Provenances in the Northcentral Nebraska (#1) and Northern High Plains clusters grew taller than all other cluster groupings in 14 and 12 of the 16 plantations, respectively.

There were random reversals of cluster performances within the shorter growing provenances of the Northwest (#2), Central Rocky Mountain (#4), and Southern (#6) clusters in the central-northern Great Plains and Minnesota region (table 3).

Table 3.—Rankings of cluster heights (feet) and survival (%) by plantation regional groups.

Rank	Northern			Eastern					Central					Southern		
	SASK	ND	SD	MN-1	MN-2	MN-3	MI-1	MI-2	NE-1	NE-2	NE-3a	NE-3b	NE-4	KS	OK	MO
Height (feet)																
Tallest	1 = 14.5	1 = 7.3	1 = 15.8	1 = 12.8	3 = 16.0	1 = 14.1	1 = 23.2	2 = 23.0	1 = 12.1	1 = 9.7	1 = 16.1	1 = 16.9	1 = 23.9	1 = 14.7	1 = 18.6	1 = 18.0
	3 = 12.4	3 = 5.0	3 = 13.9	3 = 12.6	1 = 15.2	3 = 13.1	2 = 22.6	1 = 22.2	3 = 11.0	3 = 7.3	3 = 13.4	3 = 13.1	3 = 22.6	3 = 9.9	3 = 14.4	6 = 17.4
	5 = 11.5	5 = 4.2	5 = 12.0	5 = 10.3	5 = 13.0	5 = 12.5	3 = 20.5	3 = 20.3	5 = 10.2	5 = 6.2	5 = 12.2	5 = 11.9	2 = 21.9	5 = 8.4	6 = 14.3	2 = 17.1
	4 = 10.0	4 = 3.7	4 = 10.2	2 = 9.8	4 = 11.0	4 = 11.7	5 = 20.0	4 = 18.6	4 = 9.8	2 = 5.2	6 = 10.8	6 = 10.9	5 = 21.2	6 = 7.7	5 = 13.3	3 = 17.0
	6 = 0.0	2 = 2.8	2 = 8.7	4 = 8.8	6 = 10.1	6 = 11.7	6 = 18.9	6 = 18.4	6 = 9.7	4 = 5.0	4 = 10.7	4 = 10.3	6 = 20.9	2 = 7.3	2 = 13.0	5 = 13.3
Shortest	2 = 0.0	6 = 2.0	6 = 5.5	6 = 8.2	2 = 10.0	2 = 8.3	4 = 17.8	5 = 18.3	2 = 7.4	6 = 4.6	2 = 10.1	2 = 9.8	4 = 20.8	4 = 7.1	4 = 11.4	4 = 14.1
x̄ height	11.7	4.3	11.8	10.4	12.8	12.3	19.2	19.0	10.5	6.2	12.1	11.9	21.6	8.7	13.7	16.3
Survival (%)																
Highest	-	1 = 63	1 = 95	3 = 61	1 = 75	1 = 65	2 = 90	1 = 78	4 = 87	3 = 44	4 = 99	1 = 100	1 = 100	3 = 89	1 = 91	1 = 96
	-	3 = 53	3 = 92	1 = 58	3 = 62	3 = 59	4 = 89	3 = 78	5 = 85	1 = 39	5 = 98	5 = 99	3 = 99	1 = 88	3 = 85	3 = 92
	-	5 = 43	5 = 75	5 = 52	5 = 57	5 = 53	3 = 83	5 = 73	1 = 83	5 = 37	1 = 97	4 = 99	5 = 98	5 = 88	5 = 81	5 = 88
	-	4 = 37	4 = 70	4 = 47	4 = 57	4 = 49	5 = 81	4 = 72	3 = 80	4 = 37	3 = 96	3 = 98	4 = 98	4 = 85	6 = 77	2 = 86
	-	2 = 10	2 = 38	2 = 12	2 = 34	2 = 30	1 = 65	2 = 71	6 = 73	2 = 25	6 = 74	6 = 85	2 = 96	6 = 70	4 = 71	4 = 84
Lowest	-	6 = 2	6 = 18	6 = 3	6 = 8	6 = 15	6 = 64	6 = 42	2 = 29	6 = 15	2 = 37	2 = 56	6 = 92	2 = 53	2 = 66	6 = 76
x̄ survival	-	38	72	50	54	50	82	71	78	36	90	94	97	83	80	87
No. proven.	58	72	72	63	66	69	75	75	79	78	79	79	50	77	40	78

Legend

Clusters	*x̄ Survival %*	*x̄ Height (feet)*	*% Plant. x̄ Height*
1 = Northcentral Nebraska	79	13.8	129
2 = Northwest	49	11.1	83
3 = Northern High Plains	78	13.9	109
4 = Central Rocky Mountain	72	11.2	88
5 = Foothills-Black Hills	74	13.4	100
6 = Southern	48	10.6	80

There was some G × E interaction (changing in rankings among cluster groupings) within the Missouri, Oklahoma, Michigan and Nebraska–4 plantations—all on the eastern edge of, or to the east and south of the central-northern Great Plains region. Specifically, there was improvement in the height growth of provenances in the Northwest (#2) and Southern (#6) clusters in the Missouri and Oklahoma plantations, and a decrease in the height growth of provenances in the Northern High Plains (#3) and Foothills-Black Hills (#5) clusters. Provenances in the Northwest (#2) cluster showed improved height growth in the Michigan and Nebraska–4 plantations; and some decrease was noted in the performances of provenances in the Foothills-Black Hills (#5) cluster (table 3).

Improvement in the height growth of provenances in the Northwest (#2) cluster in the Nebraska–4, Missouri and Michigan plantations may result from the moister, more uniform climate to the east of the mid-to-upper Great Plains. Location of the Missouri and Oklahoma plantations at lower and milder latitudes probably accounts for the improved height growth of provenances in the Southern (#6) cluster in these plantations.

Variation in the levels of differences were present in provenance performances within all clusters among plantations. These differences were most apparent in the Kansas plantation, where a heavy infestation of the tip moth insect suppressed height growth in most provenances; and in the North Dakota plantation, where competing vegetation restricted height growth of all provenances. Also, in the northern plantations, especially the Saskatchewan plantation, provenances in the more southerly clusters (Southern, Central Rocky Mountain, Foothills-Black Hills) grew slower or did not survive. In the southern plantations, provenances in the northern clusters (Northwest, Northern High Plains and Central Rocky Mountain) grew less vigorously. Provenances in the Northwest (#2) and Southern (#6) clusters were the most variable in height growth in all plantations.

A more quantitative assessment of the G × E interaction in these height data is provided by comparing Spearman's rank correlation coefficients computed for provenances within regions (northern, eastern, central, and southern) with those computed between the provenance means for the four regions (table 4). The presence of G × E interaction would be indicated by much larger coefficients within regional groups than between regional group means. These coefficients show there is some G × E interaction (regional identity in source performance); but that it is slight, because the coefficients for some plantations within a region are as low as some of the coefficients between regional means. Thus, the environment within a region may effect the height growth of ponderosa pine as much as the environment in different regions.

The array of cluster survival percentages by plantation shows a G × E interaction similar to, but less consistent than that for height (tables 2 and 3). Provenances in the Northcentral Nebraska (#1), Northern High Plains (#3),

and Foothills-Black Hills (#5) clusters show a clear pattern of higher survival percentages in most plantations, but are randomly ranked (table 3). Provenances in the Northwest (#2), Central Rocky Mountain (#4), and Southern (#6) clusters show lower survival percentages in most plantations, and are also randomly ranked. Provenances in the poorer surviving Northwest (#2), and Central Rocky Mountain (#4) clusters showed some improvement in some plantations (NE–1, –3a; MI–1), while provenances in the Northcentral Nebraska (#1) and Northern High Plains (#3) clusters showed some decrease in the same plantations (table 3).

Interpretation of G × E interaction for survival rankings and levels of differences are more complicated than for height growth because of variations in plantation cultural practices (ND), insect infestations (KS), rodent damage (NE–2), and improved survival of provenances in the Northwest (#2) and Central Rocky Mountain (#4) clusters in the Michigan–1 plantation.

Table 4.—Spearman's correlation coefficients for 15-year provenance tree heights among regional groupings of plantations.

	Northern				
	ND	SASK	SD		
ND	—	0.49	0.79		
SASK		—	.50		
SD			—		
	Eastern				
	MN-1	MN-2	MN-3	MI-1	MI-2
MN-1	—	0.67	0.51	0.45	0.39
MN-2		—	.66	.48	.39
MN-3			—	.23	.24
MI-1				—	.69
MI-2					—
	Central				
	NE-1	NE-2	NE-3a	NE-3b	NE-4
NE-1	—	0.69	0.72	0.69	0.48
NE-2		—	.75	.74	.61
NE-3a			—	.87	.68
NE-3b				—	.65
NE-4					—
	Southern				
	KS	OK	MO		
KS	—	0.58	0.50		
OK		—	.75		
MO			—		
	Between Group Means				
	North	East	Cent.	South	
North	—	0.38	0.55	0.48	
East		—	.28	.26	
Cent.			—	.69	
South				—	

Age/Age Correlations

Data in table 5 show that 2- and 3-year nursery provenance height performances are highly correlated ($r = 0.95$), but that nursery performances are not indicative of performance in the field. Height characteristics for a provenance, however, are well expressed by the 5th year in the field, with little difference between the 10- and 15-year means. These data indicate that provenances with superior height potential can be accurately identified at 5 or 10 years; this affirms the 10-year results reported by Read (1983).

These results appear to be in agreement with those of Lambeth (1980), Lambeth et al. (1983), Nanson (1967), Squillace and Gansel (1974), and Van Haverbeke (1983), who suggested that the most efficient age for selection is between 5 and 10 years, for some conifers.

Genetic Diversity and Adaptive Differentiation

This analysis, and those of Hanover (1963), Kempff (1928), Read (1980, 1983), Smith (1977), Squillace and Silen (1962), Steinhoff (1973), Weidman (1939), Wells (1964a, 1964b), and Wright et al. (1969) have demonstrated the existence of considerable genetic diversity among ponderosa pine populations from diverse regions. Genetic diversity also has been demonstrated in populations within restricted geographic regions, where elevational gradients are a primary selective variable creating genetic diversity (Wright et al. 1969). Examples include the Sierra Nevada mountains (Callaham and Liddicoet 1961, Conkle 1973), the eastern Rocky Mountains (Read 1980, 1983), the Colorado Front Range (Mitton et al. 1977), the northern Rocky Mountains of Idaho and western Montana (Madsen and Blake 1977, Rehfeldt and Cox 1975) and central and southern Idaho (Rehfeldt 1980).

This genetic diversity is manifested in traits related to growth and survival potential, morphology, phenology, biochemistry, physiology, and others. It is interpretable as adaptive differentiation or variation in response to environmental selectivity. For example, for environments in which the various selective factors are of an intermediate intensity, trees tend to be selected for survival which are intermediate in genetic constitution. Therefore, it should be expected that there would be a range of intermediate genetic constitutions viable only in the corresponding range of intermediate environmental conditions; the trees would thus exhibit a corresponding range of intermediate traits (Van Haverbeke 1968).

In some species, such as Douglas-fir *(Pseudotsuga menziesii)* and lodgepole pine *(Pinus contorta)*, adaptive differentiation occurs in response to relatively small

Table 5.—Genetic age/age correlations among 2- and 3-year nursery means for a provenance and the 5-, 10-, and 15-year regional means for 79 provenances of ponderosa pine.

	Genetic age/age correlations												
	Nursery 2	3	No. 5	East 5	Cent. 5	So. 5	No. 10	East 10	Cent. 10	So. 10	No. 15	East 15	Cent. 15	So. 15
Nursery 2	**0.95**		0.02	0.27	0.19	0.42	0.01	0.40	0.37	0.61	-.13	0.53	0.25	0.63
Nursery 3			.11	.16	.39	.52	.16	.28	.50	.61	0.03	.39	.37	.65
Region North 5				.12	.54	.48	**.95**	-.18	.37	.43	**.80**	-.11	.52	.43
East 5					-.03	.07	-.05	**.85**	.03	.36	-.12	**.81**	.06	.31
Cent.5						.67	.58	-.17	**.89**	.39	.56	-.20	**.90**	.42
South 5							.52	.02	.62	**.81**	.44	.04	.63	**.83**
Region North 10								-.22	.41	.42	**.96**	-.29	.54	.42
East 10									-.00	.31	-.26	**.86**	-.03	.28
Cent. 10										.46	.39	.02	**.93**	.50
South 10											.32	.40	.50	**.97**
Region North 15												-.37	.51	.32
East 15													-.08	.38
Cent. 15														.53
South 15														

environmental gradients; whereas, western white pine (*Pinus monticola*) adapts to an extremely broad range of environments (Rehfeldt 1984). Ponderosa pine is considered intermediate in its adaptive mode, with gentle clines and differentiation that are difficult to detect (Rehfeldt 1984).

This intermediate mode of adaptation in ponderosa pine explains the occurrence of the better survivability and growth potential of many of the provenances from the Northern High Plains and Northcentral Nebraska clusters throughout the plantations in the Great Plains region and beyond. Within this region, environmental clines are broad and gentle, with subtle changes—not greatly different from those areas in which provenances from the Northern High Plains and Northcentral Nebraska clusters originated. Therefore, it would be expected that environmental variables exerting selection pressure on trees within the areas of these two clusters would be more similar to those of the central-northern Great Plains region than, for example, those within the areas of the Central Rocky Mountain, Northwest, and Southern cluster territories.

Deneke and Read (1975) reported that elevation was the only variable tested that was significantly correlated (inversely) with height growth in the Kansas plantation of these ponderosa pine provenances. Low elevation sources in the Northern High Plains and Northcentral Nebraska clusters generally grew tallest in most of the test plantations—all of which were situated at even lower elevations. Indeed, trees from among the lowest elevation provenance origins (720, 721 and 757 of the Northcentral Nebraska cluster) grew the tallest at most test sites. They also suffered the least damage from tip moth (*Rhyacionia bushnellii* Busck) in the Nebraska–3a plantation (Dix and Jennings 1982). These provenances, and many from the Northern High Plains cluster, can be considered the most "local" of all the provenances. They possess genetic constitutions viable within the extremes of the environmental conditions present within the Great Plains and other regions where they survive and grow well. Similar findings and interpretations have been reported by Callaham and Hasel (1961), Hanover (1963), Mirov et al. (1952), and Squillace and Silen (1962).

Failure of most provenances in the Northwest cluster to survive and grow well in most plantations of the Great Plains proper is largely a result of wide disparities between the adaptive patterns of the two environments. In addition to low survivability and growth potential, these provenances showed high susceptibility to rabbit damage (Read 1971), hail damage (Read and Sprackling 1981), and Dothistroma needle blight (Peterson 1984). Apparently, environmental selection pressures are not present, or are not strong enough in the Northwest cluster region to select genotypes resistant to these factors.

The findings of Deneke and Read (1975) imply that elevational differences between the provenance origins of the Central Rocky Mountain and the Foothills-Black Hills clusters are largely responsible for the generally intermediate performance between the Northern High Plains and Northcentral Nebraska clusters and the Northwest and Southern clusters in most Great Plains plantations. These intermediate performing provenances, however, did perform better in the western and northern plantations than in the southern (KS, OK and MO) plantations, where environments are more dissimilar than the environments of their origin.

Provenances from the Northwest and Southern clusters survived and grew well in plantations to the south (OK) and east (NE–4; MO; MI–1, MI–2) of the Great Plains. In these cluster territories, environmental factors of latitude, temperature, precipitation, and perhaps others, have selected genotypes which are more attuned to these southerly and easterly locations than to the central and northern Great Plains. Therefore, to maximize adaptation of an introduced species, such as ponderosa pine, throughout much of the Great Plains and elsewhere, planting guidelines must reflect, as closely as possible, the matrix of environmental factors present in the localities of the seed origin (Rehfeldt 1984).

Best-Performing Provenances

Designation of provenances whose survival and height growth were 10% or more above their plantation means in 50% or more of the plantations yielded 24 and 14 provenances exhibiting outstanding survival and height growth, respectively (table 6, tables A 1–4 of Appendix). This characterization appeared to be reasonable to isolate the best-performing provenances. The validity of these best-performing provenances is strengthened in that all or most of them were included among the best performing provenances in North Dakota (Van Deusen 1980), South Dakota (Baer and Collins 1979), Minnesota (Tauer et al. 1974, Radsliff et al. 1981), the Black Hills of South Dakota (Van Deusen 1974), Kansas (Deneke and Read 1975), and Oklahoma (Tauer and Gardner 1978). Of these 38 provenances, a matching of provenances exhibiting the best survival and greatest height growth yielded a group of 9 provenances (720, 754, 811, 816, 821, 822, 825, 828, and 837) arrayed across the Northcentral Nebraska and the Northern Great Plains clusters (table 6).

Table 6.—Provenances and their locations whose survival and height exceeded by 10% or more the plantation means in half or more of the 16 plantations evaluated.

Provenance number	Location	North lat.	West long.	Elevation
		(deg.)	*(deg.)*	*(feet)*
	Montana			
727*	Fallon	46.9	105.2	2,650
753*	Windham	47.0	110.3	4,000
754* +	Monarch	47.1	110.8	4,550
811* +	Jordan	47.6	106.9	2,900
812*	Winifred	47.5	109.5	3,400
813*	Zortman	47.9	108.6	4,700
815*	Lewiston	47.1	109.2	4,800
816* +	Helena	46.6	111.8	4,500
821* +	Columbus	45.8	109.0	3,800
822* +	Roundup	46.2	108.4	3,800
823 +	Bighorn	46.1	107.4	2,900
825* +	Ashland	45.7	106.0	3,600
827*	Ekalaka	45.8	104.5	3,800
828* +	Camp Crook	45.6	104.1	4,000
	Nebraska			
720* +	Ainsworth	42.7	99.8	2,300
721 +	Valentine	42.9	100.6	2,700
722*	Chadron	42.7	103.1	4,300
855 +	Merriman	42.8	101.7	3,200
856 +	Arnold	41.4	100.0	2,900
	North Dakota			
702*	Medora	46.9	103.5	2,500
	South Dakota			
703*	Ludlow	45.8	103.5	3,200
704*	Reva	45.6	103.2	3,450
757 +	Rosebud	43.2	101.0	2,600
837* +	Lead	44.3	103.8	6,300
838*	Hill City	43.9	103.6	5,680
839*	Nemo	44.2	103.6	5,400
	Wyoming			
833*	Aladdin	44.6	104.3	4,000
835*	Newcastle	43.9	104.2	5,080
848*	Douglas	42.6	105.7	6,900

*Provenances whose mean survival was 10% or more above the plantation means in half or more of the 16 plantations.

+ = Provenances whose mean height was 10% or more above the plantation means in half or more of the 16 plantations.

Conclusions

ISODATA cluster, discriminant, and other analyses revealed the presence of considerable genetic diversity in ponderosa pine (var. *scopulorum*), and indicated there are important differences among provenances in their ability to survive and grow to age 15. The best surviving and tallest growing trees originated from northcentral Nebraska and southcentral South Dakota (the Northcentral Nebraska cluster) and northeast Wyoming, southwest North Dakota and southern Montana (the Northern High Plains cluster).

The presence of genotype × environment interaction among the provenances was minimal, with very little present in the central-northern Great Plains - Minnesota plantations, and some in the eastern (Michigan) and southern (Oklahoma and Missouri) plantations. This indicated that environment within a region may affect performance as much as environment in different regions.

Ponderosa pine height growth is well expressed by age 5; and genetic age/age correlations indicate provenances containing trees with superior height growth potential can be identified after 5 or 10 years in the field. Nursery performance, however, is not indicative of field performance.

The ability of provenance trees from the Northcentral Nebraska and Northern High Plains regions to survive and grow well throughout much of the Great Plains is attributed to the phenomenon of adaptive differentiation resulting from environmental selectivity. Environmental regimes within much of the central and northern Great Plains are more similar to those of the Northern High Plains than to those of the western and southern Rocky Mountains. Thus, genotypes selected by the extremes of the environments in the Northern High Plains and Northcentral Nebraska cluster territories (especially the latter in South Dakota and Nebraska) are better adapted to survive and flourish in the relatively similar environments of the Great Plains.

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Appendix

Table A-1.—Mean tree heights (feet) and survival (%) for ponderosa pine provenances in northern plantations.

Provenance		Indianhead SASK		Towner ND		Watertown SD	
no.	location	height	survival[1]	height	survival	height	survival
Northwest							
817	MT	np		4.1	10	np	np
818	MT	np		2.5-	5	np	np
819	MT	np		2.5-	22	np	np
820	MT	np		3.0	12	np	np
865	OR	0-		2.5	10	8.1-	36-
866	WA	0-		2.1	7	10.5-	55-
867	ID	0		2.9	2	7.4	22-
Northern High Plains							
703	SD	13.2*		5.3*	77*	13.0* +	100* +
722	NE	12.5		5.1*	57*	14.0*	94*
753	MT	np		4.7 +	70*	12.7	94*
754	MT	11.1		5.0*	62*	13.0* +	91* +
811	MT	13.2*		6.2*	78*	14.0* +	94*
812	MT	12.5		4.8* +	53* +	14.3*	97* +
816	MT	12.4		5.3*	52*	14.0*	97* +
821	MT	13.2		4.8* +	63*	13.9* +	86* +
822	MT	14.5*-		5.3* +	68*	15.0*	90*
823	MT	13.0* +		5.4*	55* +	14.3*	100* +
824	MT	12.8		5.6* +	53*	13.6*	98* +
825	MT	12.7-		5.8* +	53* +	14.6*	80
827	MT	11.6		5.0* +	48*	14.1*	83* +
828	MT	13.0*		5.4* +	47*	14.4*	88* +
833	WY	12.3-		5.0* +	32-	12.9	89*
837	SD	13.2* +		4.8* +	50* +	13.4*	98* +
840	SD	11.8		4.3 +	35	14.5*	75
852	NE	13.3* +		3.3-	37	12.0	94*
853	NE	10.1		4.5	35-	14.1*	94*
854	SD	12.6		4.2 +	40	14.7*	94*
855	NE	11.8		4.9* +	47*	15.1*	88* +
856	NE	9.9		5.6* +	53* +	14.3* +	84* +
Northcentral Nebraska							
720	NE	14.7*-		7.4*	66*	15.8* +	97* +
721	NE	14.8*-		7.6*	69	16.1*	94*
757	NE	14.0*-		6.9*	55*	15.6* +	95*
Central Rocky Mountain							
724	CO	9.6		3.1	30	10.6	50-
760	CO	8.8		3.4	37	9.2	78
761	CO	7.6		3.3-	58*	8.7	47-
762	CO	9.5		3.3	50*	9.0	47-
763	CO	9.5		3.7-	52*	12.4	56-
829	WY	10.1-		5.0* +	37	11.3 +	84* +
830	WY	10.9 +		4.6	42	10.3	97* +
831	WY	11.1 +		4.2 +	37	11.5 +	69 +
844	NE	np		2.9	30	9.4	78
847	WY	np		5.0* +	7	9.3	67 +
848	WY	8.8		3.3 +	43*	11.5 +	84*
849	WY	12.5		3.3	48*	11.0 +	81*
857	WY	0-		3.2 +	13	9.5	69
858	CO	11.3 +		3.1	35 +	9.4	78

Provenance		Indianhead SASK		Towner ND		Watertown SD	
no.	location	height	survival[1]	height	survival	height	survival
Foothills-Black Hills							
701	ND	11.6		4.7 +	45*	14.1*	100* +
702	ND	10.2		4.9* +	45*	13.2* +	97* +
704	SD	11.9		4.9* +	68*	13.4* +	97* +
723	NE	10.7 +		4.5	55*	12.7	53-
727	MT	13.2*		6.0* +	68*	14.2*	91* +
758	NE	9.7		4.0	35	12.3	84* +
759	NE	11.6 +		3.9 +	48*	11.9	78
764	CO	12.6 +		3.1	45*	9.5	38-
765	CO	np		3.0 +	7	6.8	28-
813	MT	12.1		5.0* +	57*	12.2	97* +
814	MT	11.6		4.9* +	53*	13.0* +	78
815	MT	12.2		4.8*	55*	14.0* +	88* +
826	MT	13.7*		5.2* +	46*-	14.7*	78
832	WY	9.9		3.8	37	13.6* +	88*
834	WY	12.5		4.8* +	42	13.3*	97* +
835	WY	11.2		4.3 +	50* +	13.8* +	81* +
836	WY	10.8		4.0	52* +	13.5*	83*
838	SD	10.4		4.2	47*-	13.7* +	90*
839	SD	10.9		4.2 +	50*	13.6* +	88*
845	NE	np		3.4	38 +	10.1-	66
846	WY	13.2* +		3.3 +	33	11.0 +	78
850	WY	10.9 +		3.8	48*	10.6 +	81* +
851	NE	10.3 +		3.6	38-	11.7	75 +
859	CO	14.1* +		3.1 +	18	9.0	38-
863	NM	8.5		0	0	4.2	13
Southern							
766	NM	0		0	0	0	0
767	NM	0		0	0	2.5	3
768	NM	0		0	0	2.6	2
860	CO	0		2.4	12	8.7	41-
861	CO	0-		1.6	3	8.8 +	33-
862	NM	0		0	0	4.8	28
864	NM	0		0	0	np	np
869	AZ	0		0	0	np	np
Plantation $\bar{x}$ height 11.7 feet				4.3 ft		11.8 ft	
Plantation $\bar{x}$ survival		----			38.4%		73.8%
Total sources		58		72		72	
				△			

Explanation: np = none planted
0 = planted, none survived
△ = plantations used in ISODATA cluster/discriminant analysis
* = provenances whose height or survival exceeded plantation mean by 10% or more
+ or - = provenance improvement or decline in height or survival relative to 10-year performance.

[1]*Accurate 15-Year survival data not available.*

Table A-2.—Mean tree heights (feet) and survival (%) for ponderosa pine provenances in eastern plantations.

Provenance no.	location	Grand Rapids MN-1 height	survival	Morris MN-2 height	survival	Lamberton MN-3 height	survival	Kellogg MI-1 height	survival	Russ MI-2 height	survival
Northwest											
817	MT	np	np	np	np	np	np	21.6	90*	22.1*	44
818	MT	np	np	np	np	np	np	22.2*	85	24.3*	64
819	MT	np	np	np	np	np	np	22.7*	95*	22.7*	72
820	MT	np	np	np	np	np	np	23.1*	100*	22.9*	72
865	OR	0-	0-	np	np	np	np	22.3* +	75	21.4*	88*
866	WA	9.8	8-	10.8-	50	11.3 +	20	22.9*	90*	23.5*	84*
867	ID	np	17	9.2 +	17	5.3	40 +	23.6*	95*	24.5*	76
Northern High Plains											
703	SD	10.8	67* +	15.2*	67*	13.5*	55*	19.6	90*	20.7	84*
722	NE	10.2 +	58*	13.2	88*	11.3	55*	20.0	90*	19.8	80*
753	MT	np	np	np	np	np	np	np	np	np	np
754	MT	10.5	42	12.2 +	92*	13.6* +	80*	19.2	80	20.4	92*
811	MT	14.2*	58* +	13.5	46	13.3	55*	21.7-	75	21.4*	72
812	MT	11.7*	83* +	13.8-	88*	12.2	65* +	20.0	90*	20.3	68
816	MT	13.1*	58*	15.2*	71*	12.8	80*	21.1-	88*	22.8*	90*
821	MT	13.8* +	58*	15.5*-	75*	14.7*	55* +	20.5	70	19.9	85*
822	MT	12.7*	83* +	15.9*	63*	15.3*-	55* +	22.4*	80	21.5*	92*
823	MT	12.1* +	58*	13.7	54	14.2*	50	21.0	65	21.1*	80*
824	MT	12.2*	75*	15.4*	63*	12.1	70*	20.9-	80	19.6	72
825	MT	13.6* +	33-	14.1* +	54	13.9*-	55*	21.8*-	85	22.1*	76
827	MT	11.5* +	75* +	14.8* +	63*	14.3*	65*	19.2	100*	19.6	96*
828	MT	11.2	75*	12.6 +	54	14.0* +	75*	20.8-	100*	18.8	100*
833	WY	10.4	83* +	14.0	42	14.1* +	40	19.8	100*	17.8	84*
837	SD	12.5*	100*	15.8*-	83*	13.5*	55*	np	np	np	np
840	SD	9.0-	50-	12.9 +	46-	12.4-	45	20.4	85	18.2	64
852	NE	9.7 +	17	13.4	33	12.4	80*	20.8	81	20.8	68
853	NE	10.9	58*	14.4*	67*	14.0* +	60*	20.9	75	19.9	72
854	SD	10.5	50-	12.3 +	54	10.2	45 +	np	np	np	np
855	NE	11.0	42	12.4	50	11.7-	50-	20.1	70	21.8*	72
856	NE	11.9* +	67*	13.3	58	11.2 +	45 +	19.0	65	19.1	44
Northcentral Nebraska											
720	NE	10.8	83* +	15.4*-	92*	14.0*	80*	23.9*	55	22.1*	80*
721	NE	11.8*	58*	15.5*-	75* +	15.0*	65*	np	np	np	np
757	NE	11.1-	33-	14.7* +	58	13.2-	50	22.5*	75	22.4*	75
Central Rocky Mountain											
724	CO	6.1-	25	10.2	29	12.2 +	44	18.8	80	16.1	64
760	CO	8.6	42 -	10.7	58 -	10.7	60*	16.8	90*	13.5	52
761	CO	8.9-	25-	11.1	79*	10.8	50	18.3 +	90*	15.6	68
762	CO	7.2	8	11.7	71* +	11.4 +	69*	17.6	95*	16.1	40
763	CO	10.3	75*	11.3	71* +	12.0	55*	17.2-	85	17.4	76
829	WY	10.9	75* +	13.8	45	10.4	15	17.3	85	18.0	92*
830	WY	8.7	50 +	12.9	71* +	12.1 +	40	16.4	100*	15.1	84*
831	WY	10.0	75*	11.1	58	11.5 +	50	19.0	100*	17.6	76
844	NE	8.0	58*	9.2 +	54	13.8* +	60*	18.3	80	15.3	72
847	WY	8.5	58* +	9.1	54 +	11.4 +	50	18.1 +	65	17.6	72
848	WY	9.2-	58*	11.3	71* +	12.6 +	70*	17.5	100*	14.3	84*
849	WY	9.4 +	25-	11.5 +	58	12.0	50	18.3	95*	18.8	92*
857	WY	7.9	33	10.8	29	10.6-	40	17.3	92*	14.6	68
858	CO	10.0 +	50-	9.8	46	12.1 +	35	18.8	90*	17.7	68
Foothills-Black Hills											
701	ND	9.6 +	83*	14.2* +	25	14.1* +	20	19.8	80	18.9	88*
702	ND	8.9-	58* +	14.0	71* +	11.2 +	65*	20.4	75	20.3	92*
704	SD	11.7* +	42	14.7*	79*	12.6	75*	19.4	100*	15.6	70
723	NE	7.4	42	12.7	75*	12.0	55*	21.0	85	19.7	64
727	MT	9.9 +	75*	14.6*	63*	15.3*	55* +	18.9	80	19.1	68
758	NE	10.2 +	42 -	13.3	46 -	10.5	45	20.2	60	19.2	76
759	NE	11.4*	42 +	13.5	58	12.6	65* +	19.9	70	19.9	52
764	CO	8.3	33 -	9.5	25	11.4 +	35	19.8	70	17.8	88*
765	CO	0	8	13.7	13	13.2	50	20.6	75	18.8	72
813	MT	12.6*	67* +	13.8	75*	14.3*	60*	20.4	70	16.8	96*
814	MT	11.8* +	67* +	12.6	71* +	11.7	50	20.4	70	17.7	76
815	MT	11.0-	58*	13.8	67*	12.4 +	60*	19.3	95*	18.2	80*
826	MT	13.1*-	67* +	14.5*	71*	14.2*	80*	19.8	75	17.8	64
832	WY	9.9	67* +	13.1	58 -	12.7	75*	19.8	100*	18.3	64
834	WY	11.7*	67* +	12.9	63* +	13.5*	65*	20.9	80	17.6	76
835	WY	10.0	58*	12.9 +	42	13.3	19	21.6	90*	17.4	96*
836	WY	11.2	50 -	11.6	71* +	14.0* +	60*	19.3	65	18.2	80*
838	SD	9.0-	83* +	12.3	75*	10.9-	70* +	20.0	83	16.6	65
839	SD	11.0	83*	14.4*	100*	13.5*	85*	18.2	90*	18.5	68
845	NE	9.0 -	58*	11.8 +	54	9.3 +	38	20.8	90*	17.9	72
846	WY	9.9	33-	12.9	83*	13.5*-	85*	19.4	85	17.6	80*
850	WY	9.9	33-	10.8	54	11.8 +	40	19.8	80	17.0	72
851	NE	9.7	58* +	12.7 +	42	14.5* +	40	20.1	90*	19.8	56
859	CO	9.2-	25-	10.9	50	9.4	30	19.6	80	19.3	63
863	NM	0	8	0	0	10.1 +	6	19.9	85	18.7	52
Southern											
766	NM	0	0	0	0	0	0	19.9	55	18.1	16
767	NM	np	np	0	0	0-	0	19.5	25	20.5	30
768	NM	np	np	0	0	0	0	17.8-	58	20.6	42
860	CO	8.2-	8	9.8 +	17	11.2	50-	18.7 +	75	16.6	60
861	CO	0-	0	10.3	38	9.4 +	40	17.3-	81	18.0	80*
862	NM	0	0	np	np	np	np	17.4-	85	17.4	64
864	NM	0	8	0	0	10.1	10	19.6	65	18.1	20
869	AZ	np	np	0	4	10.7	5	20.8	70	18.3	28
Plantation x̄ height		10.4 ft		12.8 ft		12.3 ft		19.9 ft		19.0 ft	
Plantation x̄ survival			48.9%		54.0%		50.2%		81.5%		71.0%
Total sources			63		66		69		75		75

Explanation: np = none planted
0 = planted, none survived
△ = plantations used in ISODATA cluster/discriminant analysis
* = provenances whose heights or survival exceeded plantation mean by 10% or more
+ or- = provenance improvement or decline in height or survival relative to 10-year performance.

Table A-3.—Mean tree heights (feet) and survival (%) for ponderosa pine provenances in central plantations.

Provenance no.	location	Alliance NE-1 height	survival	Halsey NE-2 height	survival	Hastings NE-3a height	survival	Hastings NE-3b height	survival	Plattsmouth NE-4 height	survival
Northwest											
817	MT	7.3+	33	5.5	32+	9.4	22	9.0	58	np	np
818	MT	7.6	28	5.4	22	8.8	18	8.2-	31	np	np
819	MT	6.6	30	5.7	27	11.1	88	11.1	75	22.1	97
820	MT	7.3+	33	4.7	23	10.4	28	10.8	67	21.7	95
865	OR	8.4	23	6.2	28	9.8	18	8.9-	37	np	np
866	WA	7.3+	28	4.9+	18	9.3	60-	9.9	69	np	np
867	ID	7.5+	28	4.2	23-	11.6	27	10.7	53-	np	np
Northern High Plains											
703	SD	11.1	83	7.3*+	45*-	13.1	100*	12.6	100	np	np
722	NE	10.9	87*	7.8*	58*	12.9	98*	13.5*+	97	np	np
753	MT	8.4	72	6.3	48*+	12.0	80	10.0-	100	np	np
754	MT	10.3	92*	7.8*	55*	13.3*	98*	13.1*+	100	np	np
811	MT	10.8	85	6.6	65*	14.2*	98*	13.4*	100	23.5-	100
812	MT	11.0	78	6.4	43*	12.4	97	12.9	100	np	np
816	MT	10.4	77	7.6*	60*	13.1	98*-	13.0	100	22.8	100
821	MT	10.5	83	6.7	48*	13.4*	100*	13.0+	97	np	np
822	MT	11.6*+	83	7.6*	43*	14.6*	98*	13.1*	100	24.1*	100
823	MT	10.5	80	7.4*	65*	13.4*	100*	13.0+	95	np	np
824	MT	11.1	88*	7.4*	32+	13.3*	98*	12.8	100	23.4	100
825	MT	11.4	75	7.3*	47*+	14.1*	100*	14.7*	100	np	np
827	MT	11.1	72	7.6*	43*	13.2	98*	12.7	100	22.7	100
828	MT	11.6*	81	7.4*	27-	12.4	99*+	11.9	100	np	np
833	WY	11.5*+	95*	6.6	38	13.6*	100*	13.6*	100	21.7	98
837	SD	11.7*+	80	7.0*+	48*	13.6*	100*	12.5-	100	21.1	97
840	SD	11.0	85	7.3*	40*+	13.1	98*	13.8*+	100	22.9	98
852	NE	11.2	80	7.4*	45*	14.1*	100*	14.0*	100	22.0	100
853	NE	10.9	68	8.1*+	37	13.1	98*	13.8*+	100	22.5	100
854	SD	10.9	83	7.6*+	27	13.6*	100*	13.3*+	100	22.4	98
855	NE	12.0*	70+	8.0*+	35	14.2*	78	14.5*+	94	np	np
856	NE	11.4	73	6.8*+	22	13.0	82+	13.0+	72	21.8	97
Northcentral Nebraska											
720	NE	11.3+	77	9.1*	45*	17.0*	98*	16.7*	100	23.7*	100
721	NE	12.2*	85	7.0*+	20	15.7*	100*	17.2*+	100	24.0*	100
757	NE	12.7*	87*	9.5*	52*	15.5*	93*	16.8*+	100	np	np
Central Rocky Mountain											
724	CO	9.9	87*	5.3-	35	11.3	97	10.9	100	np	np
760	CO	9.0	92*	5.3	58*	9.2	100*	9.9	100	16.2	98
761	CO	9.8	87*	5.1	62*	9.9	97	10.2	100	np	np
762	CO	10.3	92*	6.6	32	10.2	100*	9.8	100	20.5	98
763	CO	10.1	83-	5.5	35	10.5	98*	10.9+	100	20.0	100
829	WY	9.5	87*	5.5	37	12.0	100*	11.7	100	20.2	98
830	WY	9.3+	85	5.0	40*	10.7	100*	10.2	95	np	np
831	WY	9.4+	80	5.0	30	10.4	100*	10.1	100	19.3	100
844	NE	10.4	97*	5.1	28	10.4	97	9.2	99	np	np
847	WY	10.6	85	4.4+	30	11.6	100*	9.7-	97	np	np
848	WY	9.4+	80	4.2-	35	10.5	100*	9.7	97	19.0	98
849	WY	10.0	92*	4.6	37	12.4	100*	11.8	100	21.3	100
857	WY	9.6+	88*	4.6+	28	10.0	100*	9.2	100	17.5	95
858	CO	9.5+	87*	4.6	27	11.0	97	10.8	100	np	np
Foothills-Blackhills											
701	ND	10.8-	80	5.8	37	12.5	98*	13.9*+	100	np	np
702	ND	9.9	87*	6.5	40*	12.0	98*	11.6	100	21.9	100
704	SD	10.4	73	6.2	52*	12.9	95	13.2*+	100	20.8	100
723	NE	10.5	88*	7.4*+	43*	12.4	98*	12.1	100	22.1	98
727	MT	10.3	93*	6.8*+	30	11.7	100*	11.6	100	np	np
758	NE	11.1	83	6.7-	43*	11.5	100*	12.1	100	21.8	100
759	NE	10.7	85	6.2	27	13.2	100*	12.6	100	np	np
764	CO	10.8	92*	5.8	40*+	13.1	98*	11.1	100	21.0	100
765	CO	10.8	83	6.0	32+	12.1	95	11.9	92	22.1	100
813	MT	10.4	80	5.8+	40*-	11.7	98*	12.4	100	19.4	100
814	MT	10.5	83	6.0+	38	12.8	100*	12.3	100	np	np
815	MT	11.2	87*	6.2	38	12.0	98*	12.2	100	21.8	98
826	MT	9.8	80	5.4-	33+	12.4	95	12.7	97	22.2	100
832	WY	10.6	92*	6.9*	25	13.4*	98*	11.4-	100	22.7	100
834	WY	11.8*	97*	5.9	33	11.7	97	12.2	100	20.4	93
835	WY	11.3	87*	5.6	27	12.7	100*	11.6	100	21.6	98
836	WY	11.3	92*	6.2	37	12.6	97	11.7	97	np	np
838	SD	10.7	82	6.6	53*	11.4	98*	11.5	100	20.2	95
839	SD	11.3+	78	6.6	28	12.4	100*	11.3	100	np	np
845	NE	9.7+	85-	5.7	55*	12.1	100*	10.9	100	20.2	100
846	WY	11.3+	95*	6.5	37	11.5	98*	10.9	100	20.9	97
850	WY	11.1	85	6.0	48*	11.5	100*	11.2	100	np	np
851	NE	10.4	80	5.9	52*	12.0	100*	11.4	100	21.5	100
859	CO	10.7	90*	6.2	22	11.4	97	11.4	100	19.8	90
863	NM	9.8	60	5.7+	15	12.2	97	12.7	100	22.2	98
Southern											
766	NM	9.8	57	3.4	3	11.2	85	10.6-	89	21.4	88
767	NM	9.6	63	0	0	11.2	58-	9.5-	61	21.3	90
768	NM	10.5	75	4.6+	3	10.0	32	10.7	75-	22.2	97
860	CO	9.7	87*	6.0	35	10.9	100*	11.9+	100	19.8+	92
861	CO	9.1	85	4.4	47*+	11.1	100*	11.0	100	20.3	98
862	NM	9.9	92*	6.0	18	10.4	95*	11.6+	100	19.8	97
864	NM	9.1	75	3.9	12	10.9	78-	11.4+	100	21.4	93
869	AZ	9.6+	53	4.0	3	9.9	40	10.6-	53	21.3	83
Plantation x̄ height		10.5 ft		6.2 ft		12.1 ft		11.9 ft		21.6 ft	
Plantation x̄ survival			77.8%		35.7%		88.9%		93.6%		97.4%
Total sources		79		79		79		79		50	
		Δ		Δ				Δ			

Explanation: np = none planted
0 = planted, none survived
Δ = plantations used in ISODATA cluster/discriminant analysis
* = provenances whose heights or survival exceeded plantation mean by 10% or more
+ or - = provenance improvement or decline in height or survival relative to 10-year performance.

Table A-4.—Mean tree heights (ft) and survival (%) for ponderosa pine provenances in southern plantations.

Provenance		Milford KS		Norman OK		Columbia MO	
no.	location	height	survival	height	survival	height	survival
Northwest							
817	MT	8.9	42	np	np	16.5	65
818	MT	5.8	33	np	np	17.5-	100*
819	MT	6.8	58	np	np	16.6	86
820	MT	8.4+	62	13.4	52	17.1	90
865	OR	np	np	np	np	16.5	78-
866	WA	7.8	78	12.6	80	18.0*	98*+
867	ID	6.1+	43	np	np	17.2	83
Northern High Plains							
703	SD	8.3	92*	np	np	16.1	89
722	NE	9.7*+	88	14.3	97*	16.7	95
753	MT	np	np	np	np	np	np
754	MT	10.9*	93*	12.9	85	15.7	93
811	MT	9.6*	93*	14.7-	97*	17.0	96*+
812	MT	9.4	93*	np	np	17.1	98*+
816	MT	9.8*	92*	13.6	88*+	17.1-	90
821	MT	9.4	96*	14.3	97*	16.5	95
822	MT	10.6*	97*	np	np	18.3*	83
823	MT	10.2*	88	np	np	17.3	84
824	MT	9.4	87	np	np	17.0	94
825	MT	10.7*	98*	15.4*	93*	17.7-	96*+
827	MT	9.6*	98*	np	np	17.7-	90-
828	MT	9.7*	93*	np	np	17.0	91
833	WY	8.6	95*	np	np	16.9	81
837	SD	8.9	90	12.6	92*	16.8	93
840	SD	9.3	77	13.3	73	17.0	92
852	NE	9.6*+	93*	13.7	80	16.8	95
853	NE	10.9*	95*	np	np	17.0	94
854	SD	10.5*	77+	np	np	17.8-	100*
855	NE	11.6*+	77+	16.3*	68	17.4	90
856	NE	10.5*	55	16.9*-	70	16.6	83
Northcentral							
720	NE	16.0*	88	18.6*	100*	18.6*	100*
721	NE	14.4*	85	18.1*	82	17.8	89
757	NE	13.8*	91*	np	np	17.5	98*+
Central Rocky Mountain							
724	CO	8.1	80	12.7+	67	15.2	83
760	CO	5.9-	93*	9.5	73	11.6+	83
761	CO	6.3	90-	np	np	13.4	78-
762	CO	7.0	80	11.6	67	14.7+	73
763	CO	7.5	80	np	np	14.0	80+
829	WY	8.1	90	np	np	15.9	90
830	WY	6.9	88	11.2	72	14.1	88
831	WY	8.0	85	np	np	14.1	90
844	NE	7.1	77	np	np	13.6	68
847	WY	6.6	68	np	np	14.8+	89
848	WY	6.3	87	np	np	13.6	93
849	WY	7.5	88	12.4+	75	14.7	90
857	WY	6.7	93*	10.0	88*	12.6	78-
858	CO	7.8+	85	11.9	52	14.8+	100
Foothills-Black Hills							
701	ND	8.8	87	np	np	16.6	88
702	ND	7.9	93*	12.7	78	16.1	93
704	SD	8.9	97*	13.9	95*	16.6	95
723	NE	9.4	92*	12.9	73	15.9	91
727	MT	8.0+	80	np	np	15.6	69
758	NE	8.2+	88	13.2	68-	16.5	84
759	NE	9.4	87	np	np	16.4	82
764	CO	8.9	92*	12.3	77	16.1	88
765	CO	9.5-	95*	13.5	85	18.0+	95
813	MT	8.2	89	np	np	14.6+	86
814	MT	8.9	85	np	np	15.5	84
815	MT	7.3	93*	np	np	16.9	94
826	MT	8.6	73	13.4	82	16.2	96*+
832	WY	9.7*	95*	13.1	92*	16.5	95
834	WY	8.2	91*	np	np	15.1	77
835	WY	8.3	88	12.6+	82	16.7	98*+
836	WY	7.6	84	np	np	15.8	88
838	SD	8.4	82	np	np	15.5	100*
839	SD	7.7-	88	np	np	15.0	83
845	NE	7.3	93*	np	np	15.1+	88
846	WY	9.3-	90-	np	np	15.2	78-
850	WY	8.7	86	np	np	16.3	90
851	NE	8.8	90-	np	np	16.7	100*
859	CO	7.0	65	np	np	15.2	77-
863	NM	8.1+	85	15.1*+	82	16.9	88
Southern							
766	NM	6.7+	40	14.2	73	17.6	43
767	NM	7.1	63	15.2*+	73	18.2*	63
768	NM	8.6	65	17.3*-	82	18.1*+	79
860	CO	7.7	68	13.5	77	16.4	93
861	CO	7.6-	92*	12.2-	90*	16.4	79
862	NM	7.8	86	12.9+	82	16.7	100*
864	NM	8.7	88	15.0+	85	17.9*+	75
869	AZ	7.6	60	14.2	57	18.1*	78
Plantation x̄ height		8.7 feet		13.7 ft		16.3 ft	
Plantation x̄ survival			82.8%		79.5%		87.3%
Total sources			77	40		78	
			Δ			Δ	

Explanation: np = none planted
0 = planted, none survived
Δ = plantations used in ISODATA cluster/discriminant analysis
* = provenances whose height or survival exceeded plantation mean by 10% or more
+ or - = provenance improvement or decline in height or survival relative to 10-year performance.

Van Haverbeke, David F. 1986. Genetic variation in ponderosa pine: A 15-year test of provenances in the Great Plains. USDA Forest Service Research Paper RM–265, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Survival was highest and height growth greatest in ponderosa pine provenances from northcentral Nebraska, southwest South Dakota, and the High Plains region. Genotype × environment interaction was minimal in central and northern Great Plains plantations. Age/age correlations indicate provenances expressing superior height growth can be identified after 5 or 10 years.

Keywords: Ponderosa pine, *Pinus ponderosa*, provenance, seed sources, age/age correlations, genotype × environment interaction, adaptive differentiation

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526