TEN-YEAR PERFORMANCE OF DOUGLAS-FIR PROVENANCES IN EASTERN NEBRASKA

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ABSTRACT--Seedlings from 55 seed sources were established in a field test as 1+1+1 potted transplants on a silt loam soil near Plattsmouth, Nebraska. Mortality was 76 percent in the nursery the first year, increased to 89 percent for potted seedlings the second year, and reached 98 percent 1 year after field planting. All coastal types died and survival was low for north-central provenances. Arizona and New Mexico seed sources gave the best survival (20 percent). Height-latitude correlation was r = 0.81, southern Colorado, New Mexico, and Arizona seed sources grew best. Some north-central provenances have grown well in recent years. Spring growth flush is earlier in southern than in northern material. The pattern agrees with the spring frost pattern in Michigan: southern sources are damaged while northern sources are not. In Nebraska the southern material suffered fall frost damage perhaps as a result of delayed growth cessation. A Durango, Colorado, provenance is recommended for landscape, greenbelt, and Christmas tree plantings in eastern Nebraska. A Mt. Lemmon, Arizona, provenance is recommended for Christmas trees in eastern Nebraska sites protected from spring frosts and winter winds.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the most important commercial timber tree in the United States. In this paper, however, we speak of Douglas-fir not for timber purposes but as a tree for the enhancement of the environment and for use as Christmas trees. The Great Plains region of North America needs conifers for protection and for ornamental purposes, and Douglas-fir trees can help fulfill these needs in selected locations if the source of the seed is carefully chosen.

A study to identify better adapted seed origins of trees for planting in the central Great Plains is being conducted as part of the Cooperative Regional Tree Improvement Project (NC-99) of the North Central States Agricultural Experiment Stations. Credits go to Jonathan W. Wright, Professor of Forestry, Michigan State University for initiating the study

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and providing planting stock, and to Walter T. Bagley, Associate Professor, Department of Forestry, University of Nebraska, for cooperation in planting and maintaining the plantation.

PAST RESEARCH

Douglas-fir has been successfully introduced in Europe. The interior (Rocky Mountain) variety has been planted in mountainous areas with severe climates and the coastal form restricted to milder climates of England and parts of Germany (Frothingham 1909). In the United States, rangewide provenance tests east of the Rocky Mountains have consistently revealed that West Coast origins are highly susceptible to winter damage and that trees from southern Rocky Mountain origins grow fastest.

Figure 1.--Natural distribution of Douglas-fir, and provenances tested in eastern Nebraska. Origin numbers denote those that have survived; black circles, those that died in the first 3 years (Little 19711).

Geographic patterns of variation within the range of the species (fig. 1) have been recognized but there is some lack of agreement on them. Frothingham (1909) divided the range into five silvical regions: (1) North coast, (2) Sierra, (3) Northern Rockies, (4) Central Rockies, and (5) Southern Rockies. The first two comprise the area known as var. menziesii, and the other three are in the regions of var. glauca.

Wright et al. (1971) delineated 8 to 10 geographic areas based on performance in 3- to 8-year-old provenance plantations in Michigan and Nebraska. Some of these groups were similar to Frothingham's pattern and others were not. Arizona and New Mexico sources grew tallest and had bluer foliage at 8 years of age, but were damaged by winter cold in the Michigan plantings. Origins from west of the Cascades suffered extreme winter damage, and practically all of them died in the nursery.

Heit (1968) recognized three separate forms of Douglas-fir based on a New York nursery study of seedlings from range-wide sources. He referred to a Pacific Coast form viridis (now var. menziesii); a continental inland form caesia (presumably northern Idaho, Montana, and northern Wyoming); and a lower Rocky Mountain form glauca (remainder of range from central Rockies southward). Heit found, that of 11 interior origins, those from Coconino National Forest, Arizona, and the Carson National Forest, New Mexico, grew fastest and had the bluest foliage. A Montana origin of the Lewis and Clark National Forest grew slowest, and Colorado origins had average growth. He concluded that southern origins grew later into the summer when annual growth ceased for others, and that frost damage to these origins as seedlings was light and temporary because they grew normally the following season without any apparent leader deformity.

A Pennsylvania test of 19 origins from the Pacific Coast to the Rockies resulted in 55 percent mortality in western Washington and Oregon origins, compared to 21 percent for those from Colorado and New Mexico. Yet growth rate of surviving Pacific northwest trees slightly exceeded that of interior origins. Late spring frosts damaged interior origins, but they recovered rapidly and grew well (Byrnes et al. 1958).

Gerhold (1966) tested 67 of Wright's origins in a nursery near Potters Mills, Pennsylvania. West Coast origins were severely damaged by winter cold but the survivors were tallest of all origins at age 3. As in Wright's study, the Arizona and New Mexico origins outgrew other interior origins but suffered more winter injury.

Past studies all seem to indicate that the natural range of Douglas-fir in the United States is composed of the following groups: (1) Pacific Coast, (2) northern Rockies (and Wright's inland Empire), (3) central Rockies, and (4) southern Rockies. Moreover, all studies appear to indicate that the Pacific Coast variety does not survive east of the Rockies, and that the southern Rocky Mountain origins grow fastest.

The performance of Douglas-fir origins in eastern Nebraska reported here updates the first report by Wright et al. (1971) of the 55 origins tested in Nebraska, with 5 additional years' growth, and new information on spring growth flushing and winter damage to terminals.

METHODS

Seeds were collected from 128 natural stands throughout the range of the species in United States and Canada and sown in spring 1962 in a Michigan State University nursery near East Lansing. One year later, 30 to 60 seedlings each of 55 origins were sent to Lincoln, Nebraska, where they were lined-out in a holding bed (table 1). In spring 1964, the 1+1 transplants were dug, potted, and lined-out again at the same location to increase their size.

In spring 1965 they were field planted as 1+1+1 stock at the Horning State Farm near Plattsmouth, Nebraska. The plantation is located on a ridge top of silt loam derived from loess, at 41°N,96°W, and 1,100 feet elevation. Growing season averages 170 days and mean annual precipitation is 30 inches; 75 percent falls during the growing season. Seedlings were planted in one-tree plots at a spacing of 12 by 12 feet Eastern redcedar (*Juniperus virginiana*) fillers were planted for early protection between each Douglas-fir in the rows (but not between rows) to give a spacing of 6 by 12 feet.

The site was cultivated 1 year before planting, and Simazine 80W at 4 lbs per acre was sprayed on both sides of each tree row after planting to control weeds, and for 5 years thereafter. The plantation was mowed between rows during the growing season. The trees were checked several times each year for insects, diseases, and other injury. Heights were measured annually from 1966, except for 1972. The eastern redcedar fillers were removed in spring 1974 to prevent excessive crowding.

Trees were rated on two dates in spring 1974 and on four dates in spring 1975 as to the developmental stage of buds and growth of new shoots and needles. Each tree was given a phenology rating on a scale of 1 to 5, ranging from dormant buds to well advanced shoot and needle growth. An estimate of the sequence in which the different origins start spring growth was obtained by using the ratings of the one date each year that showed the greatest spread in values.

Average needle length was computed from five measurements of needles collected from lateral branches on the south side of each tree, and cone production was evaluated by counting all cones in August 1975.

Table 1.--Data on seed origin locations of Douglas-fir tested in eastern Nebraska

COAST VAR. MENZIESII

Michigan State Univ. origin No.	State or Province	Place	North latitude	West longitude	Elevation
			Degrees	Degrees	Feet
1634	VAN	Cowichan L.	48.8	124.0	600
1620	WA	Camano	48.2	122.3	50
1617	WA	Granite Falls	48.1	122.0	600
1623	WA	Enemclaw	47.2	122.0	1,308
1627	WA	Shelton	47.2	123.4	320
1624	OR	Jewell	45.8	123.4	700
1621	OR	Molalla	45.2	122.2	100
1618	OR	Cascadia	44.4	122.7	800
1585	OR	Sisters	44.3	121.8	3,500
1622	OR	Cottage Grove	43.8	123.0	675
1613	OR	Oakridge	43.7	122.5	3,000
1619	OR	Brookings	42.0	124.2	162
*1645	WA	Fish Lake	48.6	119.7	2,000
*1646	WA	Buck Mtn.	48.4	119.8	5,000
ROCKY MOUNTAIN VAR. GLAUCA (WEST OF CONTINENTAL DIVIDE)					
1556	WA	Curlew	48.9	118.8	4,100
1651	WA	Omak	48.6	119.5	2,500
*1615	ID	Coeur d'Alene	47.7	116.8	2,400
*1588	ID	Wallace	47.5	116.0	3,000
*1562	ID	Clarkia	47.0	116.1	4,500
1573	ID	Moscow	46.6	116.8	2,500
*1507	MT	Libby	48.4	115.5	3,800
1517	MT	Libby	48.4	115.2	4,000
1650	MT	Whitefish	48.5	114.7	3,500
1519	MT	Whitefish	48.4	114.7	4,000
1521	MT	Kalispell	48.2	114.5	3,000
*1600	MT	Spotted Bear RS	48.0	113.0	3,680
*1616	MT	St. Regis	47.5	115.2	4,000
1603	MT	St. Regis	47.2	114.8	5,000
*1649	MT	Missoula	47.0	114.0	3,500
1504	MT	Missoula	47.0	113.8	6,000
*1520	MT	Greenough	46.9	113.4	4,000
1506	MT	Salmon Lake	47.2	113.2	5,000
*1539	MT	Big Prairie RS	47.3	113.5	4,600
1518	MT	Stevensville	46.5	114.2	4,500
1606	MT	Butte	46.0	112.5	6,500

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Table 1. continued

Michigan State Univ. Origin No.	State or Province	Place	North latitude	West longitude	Elevation
			Degrees	Degrees	Feet
ROCKY MOUNTAIN VAR. GLAUCA (EAST OF CONTINENTAL DIVIDE)					
*1595	ALB	Kananaskis	51.0	115.0	4,500
*1596	ALB	Kananaskis	51.1	115.0	5,000
1513	MT	St. Mary	48.8	113.5	4,480
*1648	MT	Big Timber	45.5	110.0	6,000
1503	MT	Absarokee	45.5	109.4	5,600
ROCKY MOUNTAIN VAR. GLAUCA (CENTRAL AND SOUTHERN ROCKIES)					
*1636	CO	Boulder	40.2	105.5	8,650
*1529	CO	Kremmling	40.0	106.5	8,000
*1532	CO	Meeker	40.2	107.9	8,200
*1630	CO	Ouray	38.2	107.6	9,100
*1525	CO	Durango	37.5	107.8	8.500
*1610	NM	Jemez RD	35.5	106.8	8,500
1546	NM	Magdalena	34.2	107.2	8,200
*1594	NM	Cloudcroft	33.0	105.8	8,670
*1602	NM	Mayhill	32.9	105.4	7,000
1614	NM	Sacramento Mtns.	32.7	105.7	8,300
*1611	UT	Panguitch	37.6	112.5	8,250
*1625	az	Fredonia	37.0	112.5	9,000
*1647	AZ	Long Valley	34.7	111.0	7,000
*1545	AZ	Globe	33.3	110.7	7,800
*1593	AZ	Mt. Lemmon	32.4	110.8	8,400

* Origins for which subsequent data are given in table 2; all other origins failed.

RESULTS AND DISCUSSION

Survival

The number of surviving trees from many of the northern origins was only one or two; this naturally limits the confidence one can place on growth performance, and should be considered when the results are interpreted.

Mortality in the temporary lineout beds at Lincoln was 76 percent the first year. At the end of the second year as potted seedlings, total mortality had increased to 89 percent. All seedlings of Coastal western Washington and Oregon origins died during the first 2 years. Three years

after field planting in 1968, mortality had reached 98 percent. Only 2 percent of the seedlings from northern Idaho, western Montana, eastern Washington, and Alberta, Canada, origins survived after 3 years in the field (table 2) .

Table 2.--Survival and height growth of Douglas-fir provenances in eastern Nebraska

Michigan State Univ. origin No.	Location	Surviving trees	Height growth: Mean ann. 1967-1974	Height growth: 10-year field	Plantation mean
		No.	Feet	Feet	Percent
1539	Big Prairie, MT	1	0.3	2.7	25
1648	Big Timber, MT	1	0.3	2.9	27
1562	Clarkia, ID	2	0.4	3.3	30
1596	Kananaskis, ALB	1	0.4	3.9	36
1595	Kananaskis, ALB	1	0.5	4.6	42
1600	Spotted Bear, MT	1	0.6	5.1	47
1649	Missoula, MT	1	0.8	6.8	62
1636	Boulder, CO	7	0.8	7.1	65
1588	Wallace, ID	7	0.8	7.2	66
1529	Kremmling, CO	2	0.8	7.3	67
1615	Coeur d'Alene, ID	2	0.9	7.4	68
1520	Greenough, MT	1	0.9	7.6	70
1646	Buck Mtn. WA	1	1.0	8.0	73
1507	Libby, MT	1	1.0	8.0	73
1532	Meeker, CO	21	0.9	8.0	73
1611	Panguitch, UT	5	0.9	8.1	74
1616	St. Regis, MT	3	1.0	8.3	76
1645	Fish Lake, WA	4	1.0	8.8	81
1625	Fredonia, AZ	8	1.0	9.1	83
1630	Ouray, CO	1	1.1	9.4	86
1525	Durango, CO	8	1.0	10.8	99
1647	Long Valley, AZ	12	1.3	11.6	106
1610	Jemez, NM	28	1.5	12.9	118
1545	Globe, AZ	4	1.4	12.9	118
1594	Cloudcroft, NM	8	1.5	13.0	119
1602	Mayhill, NM	34	1.6	13.5	124
1593	Mt. Lemmon, AZ	13	1.8	15.8	145

Survival of central and southern Rocky Mountain origins was 20 percent. Arizona and New Mexico origins had the best survival.

The excessive mortality of coast and northern Rocky Mountain origins in the first 2 years was probably because they were smaller than stock normally planted in the Plains region. Douglas-fir planting stock is usually not transplanted until seedlings are 2 years old. They are then grown another 2 years as transplants before field planting. Past experience in field planting Colorado sources in the Plains has shown that much higher survivals can be obtained if stock is 2+2.

Height and Growth Rates

Heights and growth rates (table 2, figs. 2 and 3) were correlated with latitude; trees from the southern origins grew faster than those from northern origins. Regression analysis using individual trees as a basis indicated that latitude accounted for 21 percent of the variation in tree heights. Correlation of height and latitude using origin means was $r = -0.81$.

Growth curves grouped by geographic areas show that for 5 to 6 years after planting the central and northern Rocky Mountain origins (the seven lowest curves on fig. 3) grew very slowly, but have since shown a gradual acceleration in growth. This contrasts with the performance of various pine provenance tests at the Horning farm, which normally increase their growth rate in the third year. At first the Douglas-fir planting site was open and exposed, but as redcedar filler trees and adjacent species developed, the plantation was protected from wind during both winter and summer.

All New Mexico and Arizona origins have grown rapidly since planting. Trees from Globe, Arizona, (#1545) grew fastest through 1969, but since that time have suffered winter injury and repeated loss of terminals. Mt. Lemmon, Arizona, (#1593) trees surpassed the Globe source and remained the tallest origin to date, averaging 15.8 feet.

Foliage Characteristics and Form

Needle lengths varied among and within origins, but showed no correlation with rate of height growth or latitude (table 3). Several New Mexico and Arizona trees had bluish-green foliage, but none of these origins was consistently blue-green, as reported by other investigators. Northern Rocky Mountain trees had green foliage. Branch angles, foliage densities, and compactness of crowns varied among trees within the same origin, making it impossible to recommend any particular source for its inherently superior aesthetic value.

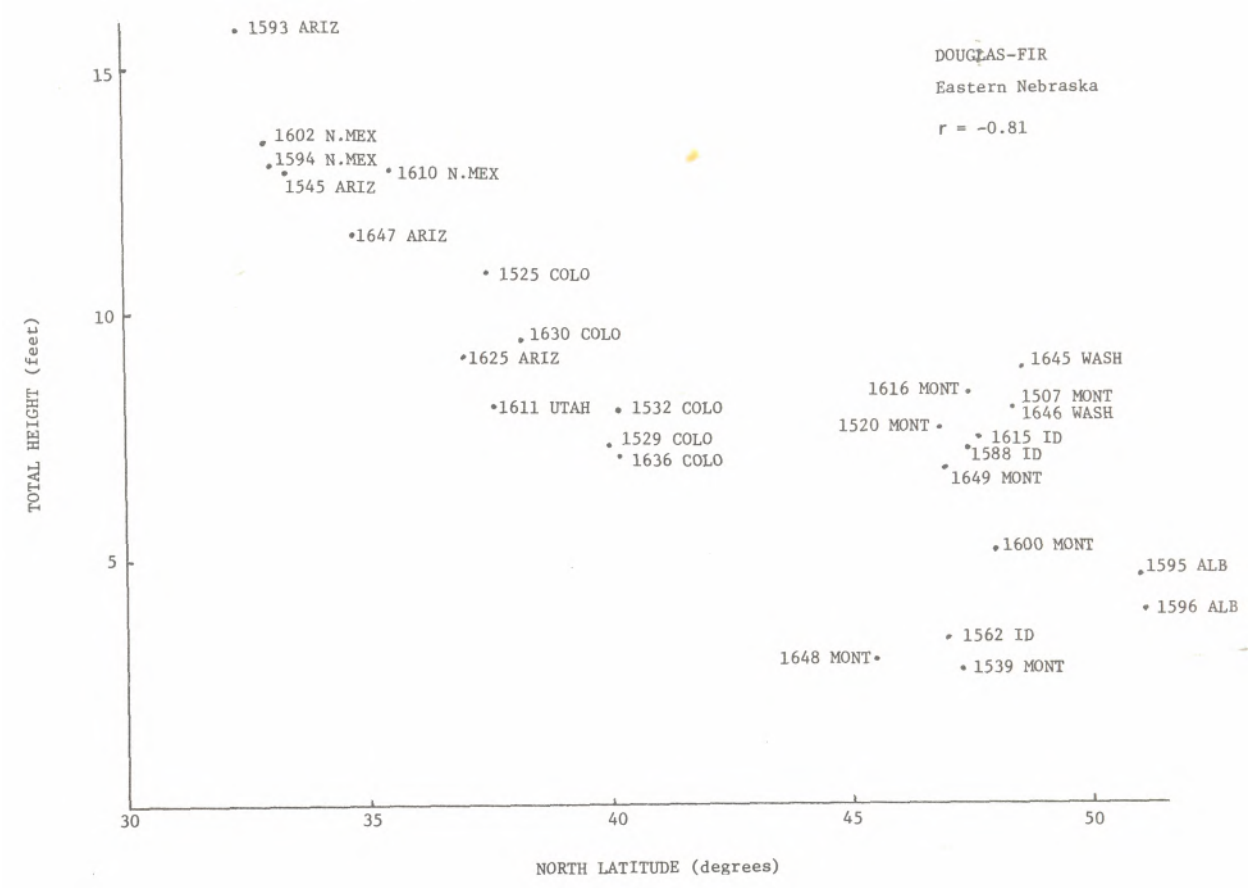

Figure 2-- Correlation of 10-year field height with latitude of origin, in eastern Nebraska.

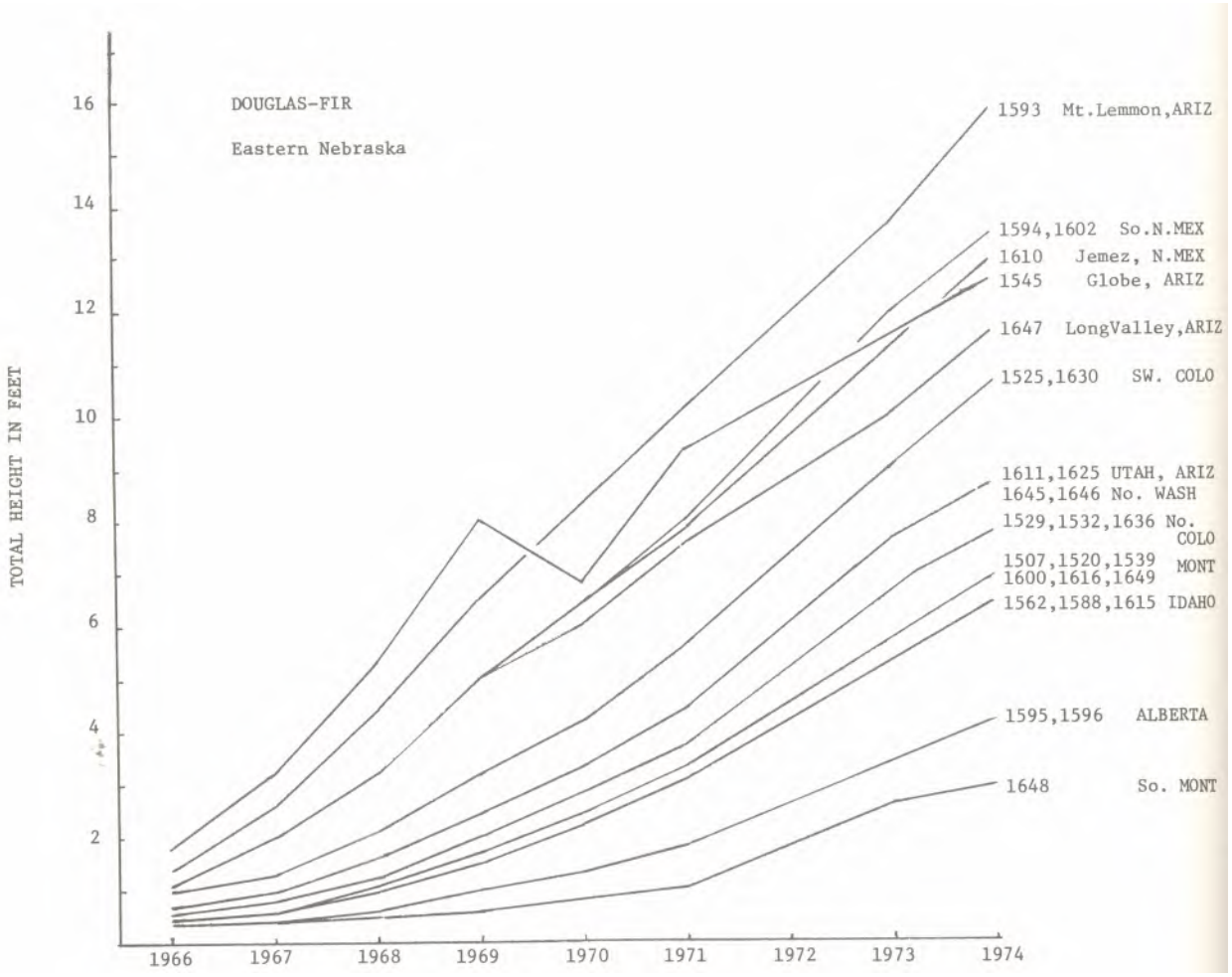

Figure 3.--Growth curves of origins (some grouped together) in the 10-year field test in eastern Nebraska.

Table 3.--Needle length, spring flushing, and terminal dieback on Douglas-fir provenances in eastern Nebraska

Michigan State Univ. origin No.	Location	Average needle length	Spring growth flushing: May 9, 1974	Spring growth flushing: May 12, 1975	Trees with terminal die back
		mm.	Code 1/		Percent
1595	Alberta	26	2.0	1.5	
1596	Alberta	25	3.0	1.5	
1507	W. Montana	28	1.0	1.5	
1616	W. Montana	28	1.7	1.0	
1600	W. Montana	28	2.0	1.0	
1649	W. Montana	28	2.0	3.0	
1520	W. Montana	28	2.0	2.0	
1539	W. Montana	31	3.0	2.0	
1588	N. Idaho	32	2.0	1.5	
1615	N. Idaho	32	2.8	1.8	
1562	N. Idaho	28	2.8	1.5	
1648	S. Montana	25	3.0	2.0	
1645	NC.Washington	32	2.9	2.0	25
1646	NC.Washington	27	4.0	3.0	
1532	N. Colorado	27	3.9	2.8	5
1636	N. Colorado	25	4.3	2.7	
1529	N. Colorado	24	4.8	3.0	
1611	S. Utah	30	3.2	2.3	
1625	N. Arizona	27	3.2	2.2	25
1630	SW.Colorado	33	2.0	1.0	
1525	SW.Colorado	34	4.5	3.5	
1610	N. New Mexico	29	3.5	2.8	39
1602	S. New Mexico	30	3.5	2.6	30
1594	S. New Mexico	32	3.8	2.8	38
1647	NC.Arizona	32	4.6	3.2	58
1545	SC.Arizona	40	4.4	3.4	100
1593	S. Arizona	30	4.1	2.9	38

1/ 1.0 = latest; 5.0 = earliest.

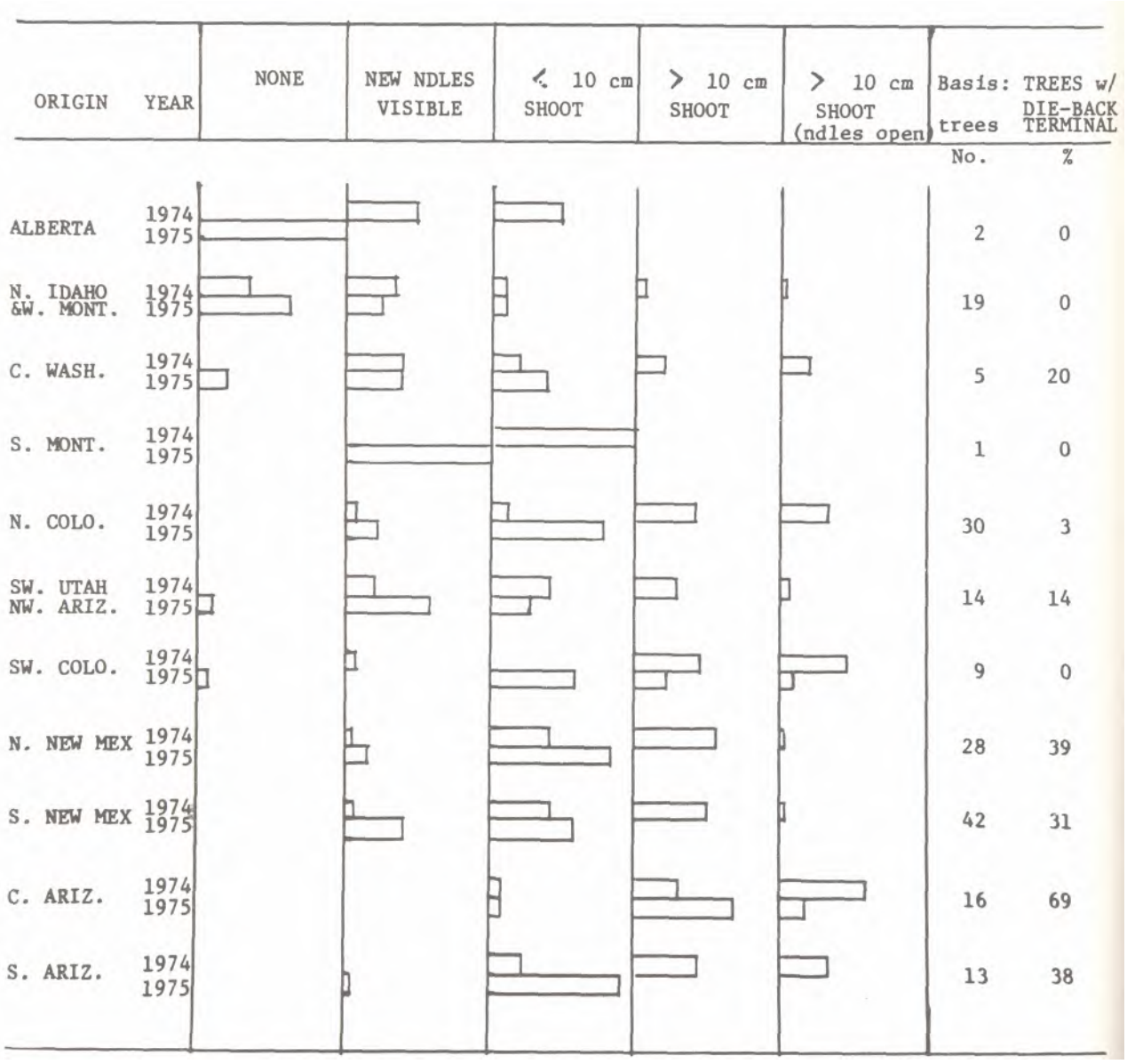

Figure 4.-- Spring growth flushing 1974 and 1975 by origins and percent of trees affected by terminal dieback.

Spring Growth Flush

Bud bursting and subsequent shoot and needle development showed widest variation by origin on May 9, 1974, and on May 12, 1975. New shoot and needle development were well advanced on most Arizona and New Mexico origins, at the same time many of the northern origins were still dormant or just beginning to flush (table 3 and fig. 4). Colorado origins tended to be intermediate. This was consistent for the 2 years, 1974 and 1975, although different spring temperature patterns in 1975 resulted in a narrowing of the rating values compared to 1974.

Steiner and Wright (1975) found this same relation in a Kellogg, Michigan, plantation at 12 years of age. Arizona, New Mexico, and Colorado origins leafed out early and were highly susceptible to late spring frost, whereas origins from western Montana and northern Idaho leafed out a month later and were not susceptible.

Munger and Morris (1936) recorded the same bud bursting activity in 13 Coastal sources of Douglas-fir, west of the Cascade Range and extending over only 3-1/2° latitude from northern Washington to central Oregon. Bud bursting was earliest on the southerly and low elevation sources, and latest on those of northern Washington.

Another point of interest is the apparent similarity in phenology of the central Washington origins with those further south in the central Rocky Mountains, rather than with origins much closer in northern Idaho and western Montana (fig. 4). Frothingham's distribution of silvical regions shows the eastern side of the Cascades through Washington in the same silvical region as the central Rockies.

These observations indicate that Douglas-fir phenology at this Nebraska latitude (41°) as related to latitude of origin, is the reverse of ponderosa pine. In a central Nebraska nursery experiment, the northern origins of ponderosa seedlings from central and eastern Montana began spring growth several weeks before origins from New Mexico (Read 1975). Despite the early growth flush of southern origin Douglas-fir in Nebraska, no damage from late spring frost has yet occurred. This is because the ridge top plantation site is sufficiently exposed to delay extremely early bud bursting and to prevent frost pockets.

Terminal Dieback

Differences in time of bud set and cessation of terminal growth were not measured. However, a possible result of differences in time of growth cessation, has been dieback of the terminals on 44 trees (about 40 percent) of the southern origins. Every Arizona and New Mexico origin showed damage on some trees, ranging from 25 percent of #1625, Fredonia, Arizona, to 100 percent of #1545 Globe, Arizona, (table 3, figs. 3 and 4) .

Trees of southern origins do not cease growth early enough to avoid frost damage in late fall. This agrees with Wright et al. (1971) who found that among interior origins growing in Michigan and Pennsylvania, southern origins set buds latest, and therefore were winter damaged, while northern origins set buds earliest and were not injured.

Campbell and Sorensen (1973) found this same relation among West Coast origins of Douglas-fir, covering only 5 degrees spread in latitude from southern Oregon to northern Washington.

It is interesting that terminal dieback did not occur until these trees were 5 to 6 years old and averaged around 7 feet in height. Increased exposure of tops to winter winds may increase susceptibility, as it was noted that dieback increased significantly during the first winter after removal of the filler trees. Winter dieback has not yet caused mortality despite its recurrence on the same trees in successive winters. Strong lateral branches grow into dominant terminals the following growing seasons (fig. 5).

Cone Production

First cones were observed in August 1975, after 11 years in the field. No measure of seed production and viability is yet available.

Six of 13 trees of the Mt. Lemmon, Arizona, source had cones ranging from 2 to 75 per tree, with a median of 7 to 8 cones. Two of 28 trees of the Jemez, New Mexico, source had 3 to 5 cones, and one of 4 trees of the Fish Lake, Washington, source had 13 cones. Initial cone production was strongly related to the tallest and largest crown trees in the plantation.

CONCLUSIONS AND RECOMMENDATIONS

This provenance test indicates that within the interior (Rocky Mountain) Douglas-fir var. glauca, there are large variations in survival, growth, and susceptibility to cold, which are strongly correlated with latitude of origin. Pacific Coast origins var. menziesii, cannot survive Nebraska winters. Northern Rocky Mountain origins have low survival rates and grow slowly. Therefore, northern Rockies and Pacific Coast origins of Douglas-fir are definitely not recommended for planting in Nebraska. Southern Rocky Mountain origins survive well and grow very fast, but individual trees suffer some cold injury. Central Rocky Mountain origins have average survival and growth, yet are not affected by cold temperatures.

Figure 5.--A #1647 central Arizona tree showing recovery from terminal dieback of the previous winter.

Douglas-fir can be grown with greatest success in eastern Nebraska, although with irrigation it probably can be grown further west in the State. Planting stock for maximum survival should have at least 8 to 12 inches top height and a fibrous root system of similar size; these will normally be 2+1 or 2+2 age class from the best nurseries. Younger potted stock may be satisfactory.

Major uses of this species in central Great Plains are for ornamental plantings and for Christmas trees. Therefore the slower growing, but winter hardy central Rocky Mountain origins may prove most successful in the long run. The Durango, Colorado, origin #1525, which has above average survival, medium growth, and no winter damage, is well adapted for landscape plantings, Christmas trees, greenbelts, and roadside parks. Central Rocky Mountain origins are not recommended for windbreaks because faster growing species of pine and juniper which give protection in fewer years, are available for this purpose.

Because of terminal dieback, the faster growing Arizona and New Mexico origins of Douglas-fir are the only ones recommended for Christmas trees. These short rotation tree crops should be a safe investment, because the winter killing of terminals in the Horning plantation did not occur until trees exceeded merchantable Christmas tree height. In planting these southern origins, it is essential to select plantation sites to avoid frost pockets where spring frost damage could occur, and wind swept areas where terminal dieback could be serious. The Mt. Lemmon, Arizona, source #1593 is recommended for Christmas tree growers in eastern Nebraska. These trees averaged 6.5 feet in height after only 5 years in the test plantation. Use of this fast growing origin will give Christmas tree growers a more rapid return on investment than slower growing trees.

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