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Growth Performance and Reaction to Biotic and Abiotic Factors of Douglas Fir Progenies (*Pseudotsuga menziesii* [MIRB.] FRANCO)[1][2]

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Summary

Seed of 24 progenies of Douglas fir (*Pseudotsuga menziesii* [MIRB.] FRANCO) from 7 states of the USA and of 1 progeny from Mexico collected within the natural range of the species was sown in 1963. In spring 1966 a field trial was established in the forest district of Nordhorn, northwestern Germany, as part of the Emsland afforestation program to test the suitability of Douglas fir progenies on former agricultural land. In the field trial several traits were measured or assessed regarding growth performance, susceptibility to biotic and abiotic agents, and volume production after 32 years of growth. Regarding these characters the provenances show a great variation and can be divided into at least 6 main groups (clusters). At the age of 32 the progenies from coastal Oregon would have produced in a pure stand 220 m³/ha. The performance of the Douglas fir progenies was compared also with tree species regenerated naturally in the field trial.

Key words: Douglas fir, single tree progenies, variation, growth characters, *Rhabdocline,* needle cast, winter frost, late frost, volume production.

FDC: 232.11; 232.12; 165.5; 174.7 *Pseudotsuga menziesii;* (430).

Zusammenfassung

Im natürlichen Verbreitungsgebiet der Douglasie wurde von 24 Einzelbäumen in 7 Bundesstaaten der USA und von einer Population in Mexiko Saatgut eingesammelt und 1963 in Großhansdorf ausgesät. Im Frühjahr 1966 wurde im Landwirtschaftskammer-Forstamt Nordhorn im Rahmen des Emslandprogramms ein Feldversuch angelegt, um die Eignung verschiedener Douglasienabsaaten bei der Erstaufforstung auf ehemals landwirtschaftlichen Flächen zu prüfen. Im Feldversuch wurden mehrere Merkmale, u.a. Wachstumsmerkmale, Anfälligkeit gegenüber biotischen und abiotischen Schadfaktoren, erhoben und die Derbholzmenge nach 32 Jahren berechnet. Die erhobenen Merkmale variieren zwischen den Douglasienabsaaten stark und erlauben eine Unterteilung der Absaaten in sechs Gruppen (Cluster). Im Alter von 32 Jahren hatten die Absaaten aus dem küstennahen Oregon rund 220 Fm/ha Derbholz produziert. Verglichen wurde auch die Derbholzmenge mit auf der Versuchsfläche natürlich verjüngten Baumarten.

Introduction

Douglas fir (*Pseudotsuga menziesii* [MIRB.] FRANCO) is the most important exotic forest tree species in German forestry and covers 1.3% of the forest area in Germany (BML, 1990, 1994). In appropriate stands Douglas fir produces far more timber than comparable native forest tree species as for example Norway spruce (*Picea abies* [L.] KARST.) (SCHOBER, 1963) or Scots pine (*Pinus sylvestris* L.) (KLEINSCHMIT, 1978). In Northwest Germany the area with Douglas fir will be increased mostly at the expense of Scots pine.

In the following paper an evaluation of a progeny test is given, which had been initiated in 1963 by KLAUS STERN during his time at the Institute for Forest Genetics at Großhansdorf. The field trial was established as part of the afforestation program in the Emsland (Northwest Germany) in spring 1966. Aim of the progeny experiment was to prove the early performance of provenances on a poor site and to compare seed lots from the northern and southern interior of the natural distribution area in the United States and Mexico. Populations of some of these regions were rarely represented in one of the numerous previous studies in central Europe. First results of this progeny test were published by HERRMANN (1973), STEPHAN (1973a and b), STERN et al. (1974) and HATTEMER and KÖNIG (1975). The present paper is based on recently collected data and on additional statistical analyses of previous data.

Materials and Methods

The 25 Douglas fir seed lots were collected in the natural distribution area of 7 states of the USA (24) and of a Mexican province (1), mainly from open-pollinated single trees. The origin of the progenies and their geographical data are given in

[1]) Dedicated to Dr. G. H. MELCHIOR on his 70th birthday

[2]) A modified version of a paper presented on the IUFRO meeting on "Evolution of breeding strategies for conifers from the Pacific Northwest" at Limoges, France, August 1 to 4, 1995.

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table 1 and are shown in *figure 1*. The seed lots were sown in 1963 in the nursery of the Institute for Forest Genetics in Großhansdorf (northern Germany).

Table 1. – Origin of seed lots for the 1966 Douglas fir progeny experiment.

no.	state	origin	latitude [°N]	longitude [°W]	altitude [m]	trees sampled
1	Montana	Kaniksu 2 (Trout Creek)	47°49'	115°38'	880	1
2	Montana	Kaniksu 2 (Trout Creek)	47°49'	115°38'	880	1
3	Montana	Glacier Park 1	48°24'	113°12'	1040	*)
4	Montana	Glacier Park 1	48°24'	113°12'	1040	*)
5	Montana	Missoula 1	46°52'	114°00'	1310	1
6	Montana	Missoula 1	46°52'	114°00'	1310	1
7	Montana	Beaverhead 2	45°26'	112°11'	1920	1
8	Colorado	Rocky Mtn.Nat.Park 1	40°23'	105°33'	2160	1
9	Colorado	Rocky Mtn.Nat.Park 3	40°41'	105°31'	2590	1
10	Colorado	Rocky Mtn.Nat.Park 4	40°02'	105°17'	2860	1
11	New Mexico	Cibola 1	34°00'	107°30'	2670	1
12	New Mexico	Cibola 2	34°00'	107°30'	2860	1
13	New Mexico	Cibola 3	34°00'	107°30'	3050	1
14	New Mexico	Lincoln 1	32°54'	105°28'	2410	1
15	New Mexico	Lincoln 2	32°54'	105°28'	2590	1
16	New Mexico	Lincoln 2	32°54'	105°28'	2590	1
17	Arizona	Coconino 2	35°00'	111°30'	2740	1
18	Arizona	Coconino 2	35°00'	111°30'	2740	1
19	Utah	Bryce 1	37°06'	111°56'	2650	1
20	Oregon	Corvallis area	44°34'	123°16'	440	****)
21	Oregon	Valsetz	44°50'	123°37'	****)	**)
22	Utah	Manti-Lasal-Forest	38°00'	109°30'	2740	**)
23	Mexico	Arteaga	25°17'	100°35'	2460	***)
24	Idaho	Owyhee 1	43°03'	116°49'	1770	1
25	Oregon	John Day	44°25'	119°00'	1220	1

*) squirrel caches
**) commercial seed
***) several trees, number unknown
****) unknown

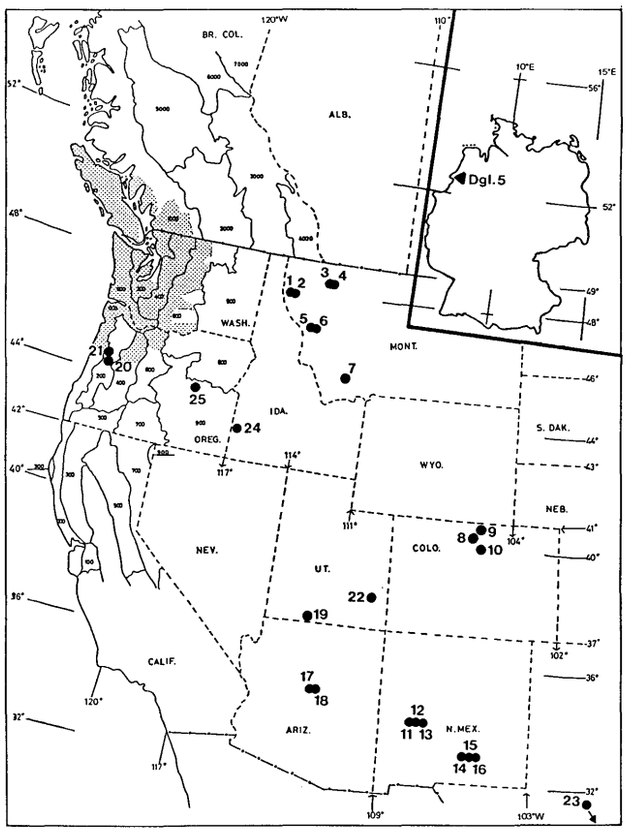

Fig. 1. – Original geographic location of the 25 Douglas fir progenies and of the field trial in Northwest Germany. The area is hatched from where an import of seed to Germany is recommended. In British Columbia, Washington, Oregon, and California the main seed zones are given.

A field trial was established with 3 year old plants in spring 1966. Details about establishment and design of the progeny test were described by HERRMANN (1973) and by STERN et al. (1974). The field trial (internal code Dgl 5) with a size of 0.6 ha is located in Northwest Germany in the forest district of Nordhorn (52°32' N, 6°44' E, 35 m above sea level).

The following traits were measured or assessed: height growth at age 5, 7, 8, 10, 14, and 32; diameter at breast height (1.3 m) at age 23 and 32; attack by the needle cast fungus *Rhabdocline pseudotsugae* SYD. at age 10, 11, and 12; damages by winter frost and late frost at age 6, 7, and 8; killed terminal buds at age 6, 7, and 8. Simultaneously the mortality was stated for each progeny. At age 32 the volume per ha was calculated.

Until the age of 32 years the field trial has never been thinned nor were the seedlings removed, which have regenerated naturally from surrounding tree species like birch (*Betula pendula* ROTH), Scots pine (*Pinus sylvestris* L.) and some others. This offered the opportunity to compare the performance and behaviour of the tested Douglas fir progenies under natural competition with a few other native tree species.

With the SAS program package (SAS Institute Inc., 1989) cluster analysis (UPGMA = unweighted pair-group method using arithmetic averages), stepwise discrimination analysis, mean values and frequencies were calculated. Depending on the trait, single tree values, plot mean values of the progeny or mean values of the progeny were used for the various calculations.

Results

Comparison of the Douglas fir progenies on base of all traits measured or assessed

There are very conspicuous differences between the 25 progenies regarding all traits measured or assessed. On the base of 18 measured or assessed traits (attack by *Rhabdocline* at age 10, 11, and 12; damages by winter and late frost at age 6, 7, and 8; killed terminal buds at age 6, 7, and 8; height growth at age 5, 8, and 10; mortality at age 5, 23, and 32) and 2 geographical data (longitude, latitude) the similarity of the 25 progenies has been investigated by cluster analysis. The resulting dendrogram is presented in *figure 2*. Two main groups can be distinquished. The first group can be divided at the similarity distance of about 0.6 into 3 subgroups of different size with the following progenies:

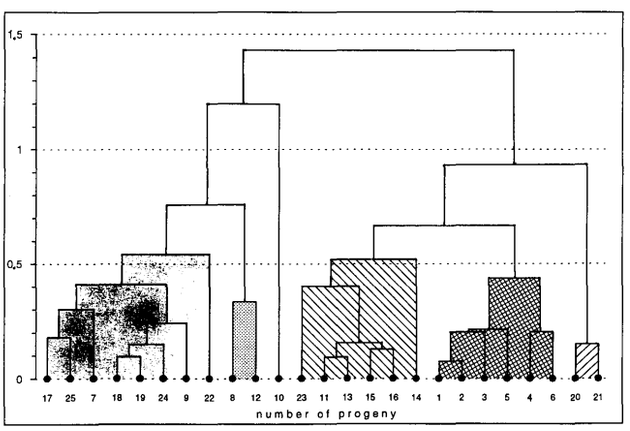

Fig. 2. – Dendrogram (cluster analysis UPGMA) illustrating the similarities of 25 Douglas fir progenies based on 18 measured or assessed traits and 2 geographical data. For the origin of progenies see *table 1*.

(1.1) 8 progenies from Montana (no. 7), Colorado (no. 9), Arizona (no. 17, 18), Utah (no. 19, 22), Idaho (no. 24) and Oregon (no. 25);
(1.2) 2 progenies from Colorado (no. 8) and New Mexico (no. 12);
(1.3) a single progeny from Colorado (no. 10).

Also in the second group 3 further subgroups can be distinguished:
(2.1) 6 progenies from New Mexico (no. 11, 13 to 16) and Mexico (no. 23);
(2.2) 6 progenies from Montana (no. 1 to 6);
(2.3) 2 progenies from Oregon (no. 20, 21).

In the following figures *(Fig. 3, 4, 6, 7, 8)* the progenies are grouped according to the results of the cluster analysis.

In general, progenies from the same region have a low similarity distance, e.g. most of the progenies from Arizona, Utah, Colorado, which belong to subgroups of the first main group, or progenies from New Mexico including Mexico, Montana and Oregon, which belong to separate subgroups of the second main group. In some cases, the single tree progenies from the same or adjacent stands (see *Table 1*) are very similar (Montana no. 1 and 2, New Mexico no. 15 and 16). In other cases the similarity distances are larger, although the progenies were from the same geographical origin (Arizona no. 17 and 18, Montana no. 5 and 6, or no. 3 and 4). These differences may result from the great variation between the single trees within a stand. In this connection it is of interest that the seed lots of Montana no. 3 and 4 were collected from squirrel caches and represent, therefore, probably more than 1 single tree of the respective stand.

Cluster analyses were calculated also on the base of only 1 value of the various traits, of the last measured or assessed value of a trait, and by omitting the geographical data for latitude and longitude. The resulting cluster analyses showed a general good correspondence with only some minor differences regarding the grouping of progenies. Comparing the values for the various traits, the similarity between progenies within the separate subgroups was highest, when also the geographical data were included in the calculations. Therefore, it was decided to arrange in the following figures the progenies according to the cluster analysis on the base of 18 biological traits together with the 2 geographical data.

Additionally, it was analysed by a stepwise discrimination model, which of the traits had the highest influence for discriminating the progenies. It could be shown that 8 of the 18 in the cluster analysis used traits had a discriminating influence (*Table 2*). These discriminating traits were:

Table 2. – Results of stepwise discriminant analysis between 18 measured or assessed traits and 2 geographical data of 25 Douglas fir progenies.

variable entered	step	F statistic	Wilks' lambda	average squared canonical correlation
Rhabdocline attack 1973	1	138.8 ***	0.0266 ***	0.195 ***
Rhabdocline attack 1974	2	69.5 ***	0.0013 ***	0.385 ***
height 1967	3	18.7 ***	0.0002 ***	0.553 ***
winter frost damage 1968/69	4	9.1 ***	0.0001 ***	0.680 ***
longitude	5	4.8 **	<0.0001 ***	0.733 ***
plant without terminal bud 1970	6	2.6 ns	<0.0001 ***	0.746 ***
plants survived until 1994	7	2.4 ns	<0.0001 ***	0.783 ***
plant without terminal bud 1969	8	2.5 ns	<0.0001 ***	0.843 ***

significances: **) ≤ 1% ***) ≤ 0.1% ns) = not significant

Rhabdocline attack at age 11 (1973) and 12 (1974), height growth until 1967 (age 5), damage by winter frost 1968/1969 (age 6), plants with killed terminal buds at age 7 (1969) and 8 (1970), geographical longitude and the number of plants which survived until 1994.

Attack by Rhabdocline pseudotsugae

The ascomycetous fungus *Rhabdocline pseudotsugae* can cause a very severe needle cast disease of Douglas fir. Obviously around 1971/1972 an epidemic started in the progeny field trial, because in June 1971 all trees were still healthy and showed no conspicuous needle attack. First and in some progenies very serious disease symptoms were detected in spring 1972. Therefore, all trees of all progenies were assessed according a 4-step scale from 0 = no attack to 3 = heavy attack (STEPHAN, 1973b).

The assessments during 3 consecutive years show a strong variability in the susceptibility of the progenies (*Fig. 3*). At the age of 10 (1972) the progenies from Oregon (no. 20, 21), Montana (no. 1 to 6), New Mexico (no. 11 to 16), Mexico (no. 23), and 1 progeny from Colorado (no. 10) were not or only weakly attacked. Progenies from Oregon, Idaho, South Montana, Utah, Arizona, and one from Colorado were severely damaged. In the following 2 years the damage by *Rhabdocline* increased, and nearly no tree of the latter 8 progenies was without damage in 1973. In the average of all progenies about 50% of the trees were heavily attacked by *Rhabdocline* in 1974. A striking increase in needle cast damage was observed in the progenies from New Mexico (no. 11 to 16) and Mexico (no. 23). Nevertheless, the damage was less than in the Arizona-Utah-Colorado group. Although needle cast symptoms were detected also in progenies from Oregon and Montana the damages were only weak during the 3 years of observation.

A comparison between the *Rhabdocline* attack assessed in the 3 years and geographical data as well as growth data of various years resulted in weakly significant negative correlation coefficients with the latitude, positive correlation coefficients with the altitude, and no correlation with the longitude (*Table 3*). Very strong and negative were the correlation coefficients for height and diameter growth. This can be on one side symptomatic of the growth reduction by the fungal disease, but on the other side also an indication that the slow growing and probably not adapted progenies were more susceptible for the disease.

Damage by winter frost and late frost

Winter frost and late frost were assessed for individual trees in 3 successive years (1967/1968 to 1969/1970) using a scale from 0 = no damage to 5 = very heavy damage (HATTEMER and KÖNIG, 1975). The winter 1967/1968 damaged the trees only slightly. In the following 2 years the damages were more severe (*Fig. 4*). In all winters the progenies from Oregon (no. 20, 21) showed the strongest frost damages followed by the progeny from Mexico (no. 23). However, the damages were very slight in progenies from Montana (no. 1 to 6). Winter frost damage was only weakly or not correlated with other traits (*Table 4*). A significant negative correlation existed with the geographical latitude as southern progenies were more attacked than northern ones. A positive weak correlation could be found with the geographical altitude. Only the damages in winter 1968/1969 were weakly correlated with the mortality until age 23 (*Table 4*).

The Douglas fir progenies were only slightly damaged by late frosts during each spring 1968 to 1970. The most severe damage occurred in 1968, when in average about 20% of all trees

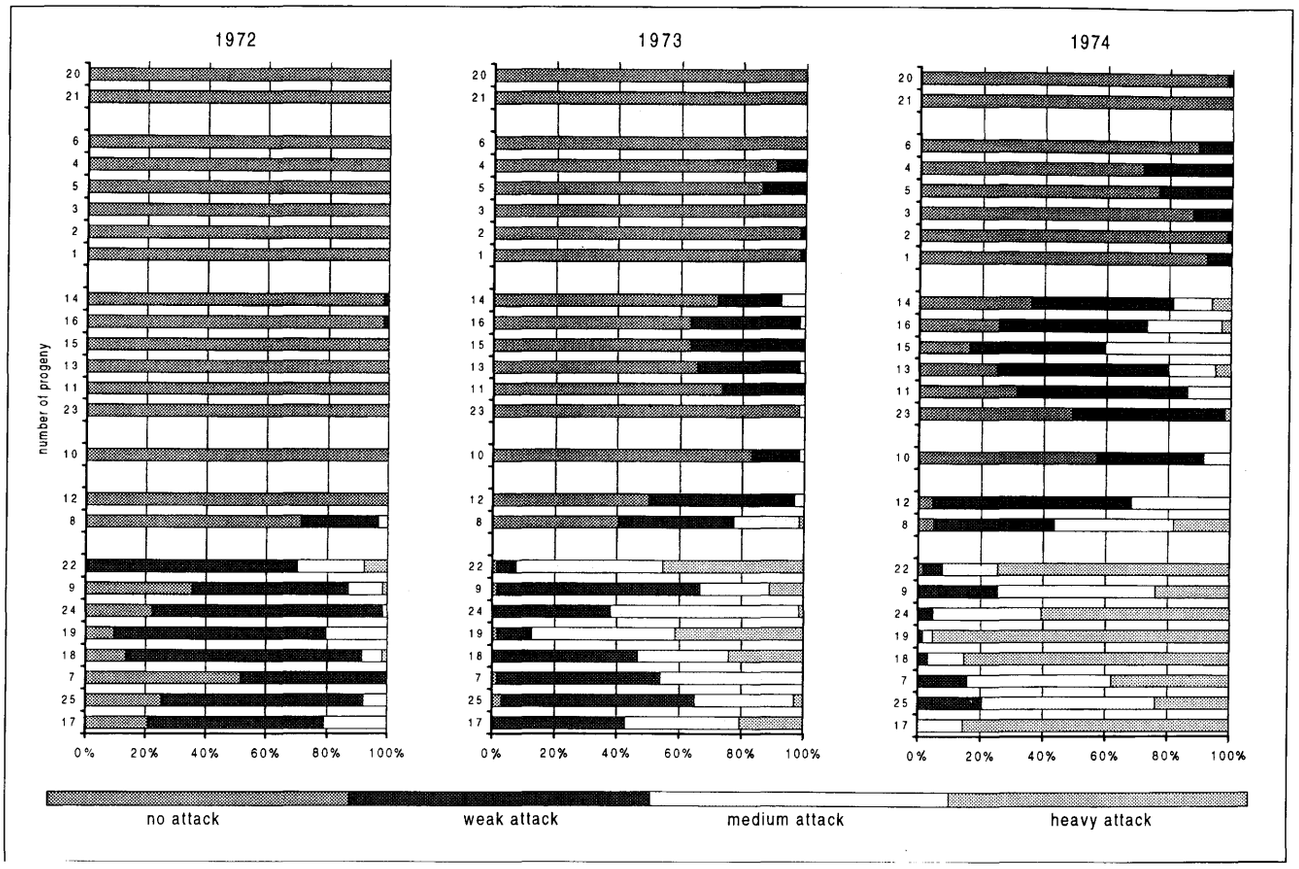

Fig. 3. – Attack of Douglas fir progenies by *Rhabdocline pseudotsugae* in the years 1972, 1973 and 1974.

Table 3. – SPEARMAN's rank correlation coefficients between the mean degree of *Rhabdocline* attack at 3 ages, and geographical and growth data compared on base of progeny means.

	latitude [°N] [1]	longitude [°W] [1]	altitude [m] [2]	mean height at age 10 (1972) [1]	mean height at age 14 (1976) [1]	mean dbh at age 14 (1976) [1]	mean dbh at age 23 (1985) [2]	mean dbh at age 32 (1994) [3]
mean degree of *Rhabdocline* attack								
at age 10 (1972)	-0.20 ns	-0.05 ns	0.28 ns	-0.59 **	-0.65 ***	-0.66 ***	-0.67 ***	-0.61 **
at age 11 (1973)	-0.42 *	-0.28 ns	0.57 **	-0.74 ***	-0.79 ***	-0.81 ***	-0.84 ***	-0.78 ***
at age 12 (1974)	-0.45 *	-0.31 ns	0.58 **	-0.75 ***	-0.79 ***	-0.80 ***	-0.88 ***	-0.86 ***

significances: *) ≤ 5% **) ≤ 1% ***) ≤ 0.1% ns = not significant
number of progenies: [1])n = 25 [2])n = 24 [3])n = 19

showed damage, 1 Oregon progeny (no. 20) even more than 60%. As in winter also in spring the Montana progenies were generally less attacked than for instance the more southern progenies. This behaviour is also expressed by highly significant correlation coefficients between late frost damage in each spring of 1969 and 1970 and the geographical latitude and longitude and by a positive correlation with the altitude (*Table 4*). Repeated late frost damage influenced obviously also the mortality rate until age 32 (*Table 4*).

Condition of health and mortality

In the years 1978 (age 16), 1985 (age 23) and 1989 (age 27) the appearance of health condition was classified three times for each plot. Most of the classified damages (needle lost, needle colour) might be caused also by *Rhabdocline* in combination with slow growth. The results of these classifications and the further development until 1989 are shown in *figure 5*. In 1978 (age 16) there were 36 from 100 plots classified as healthy with green needles and dense crowns. Together with the only slightly damaged plots 71 had a good health condition or appeared only slightly damaged. In 1985 (age 23) and 1989 (age 27) the number of plots with a good health condition or with slight damage decreased to 33 in 1985 and 23 in 1989. Between 1978 and 1985 the trees of 43 plots died. This number increased to 52 plots until 1989. No heavily damaged plot recovered during this period.

Until autumn 1994 a number of 453 (28.3%) Douglas fir trees out of 1600 planted ones were still alive. All trees of 6 progenies (no. 8, 9, 10, 12, 18, and 19) were dead in 1994. In 2 other progenies (no. 17, 22) only 1 tree was still alive (*Fig. 6*). With the exception of progenies from Montana (no. 1 to 6) and Oregon (no. 20, 21) the mortality was higher than 70%. Most of the trees of the other progenies died between 1972 and 1985. However, the progenies from Montana (no. 1 to 6) had the highest rate of mortality between 1985 and 1994, presumably due to a strong competition between the individual trees within the plots. Tree death due to competition can not be separated from other reasons of mortality.

Growth performance

Regarding the mean height until the age of 14 years (1976), the differences between all progenies were significant in all years. At age 14 the overall average value was 3.64 m. The lowest mean height was recorded for a progeny from Utah (no. 22) with 1.92 m and the greatest mean height values for the progenies from Oregon with 5.23 m (no. 21) and with 5.40 m

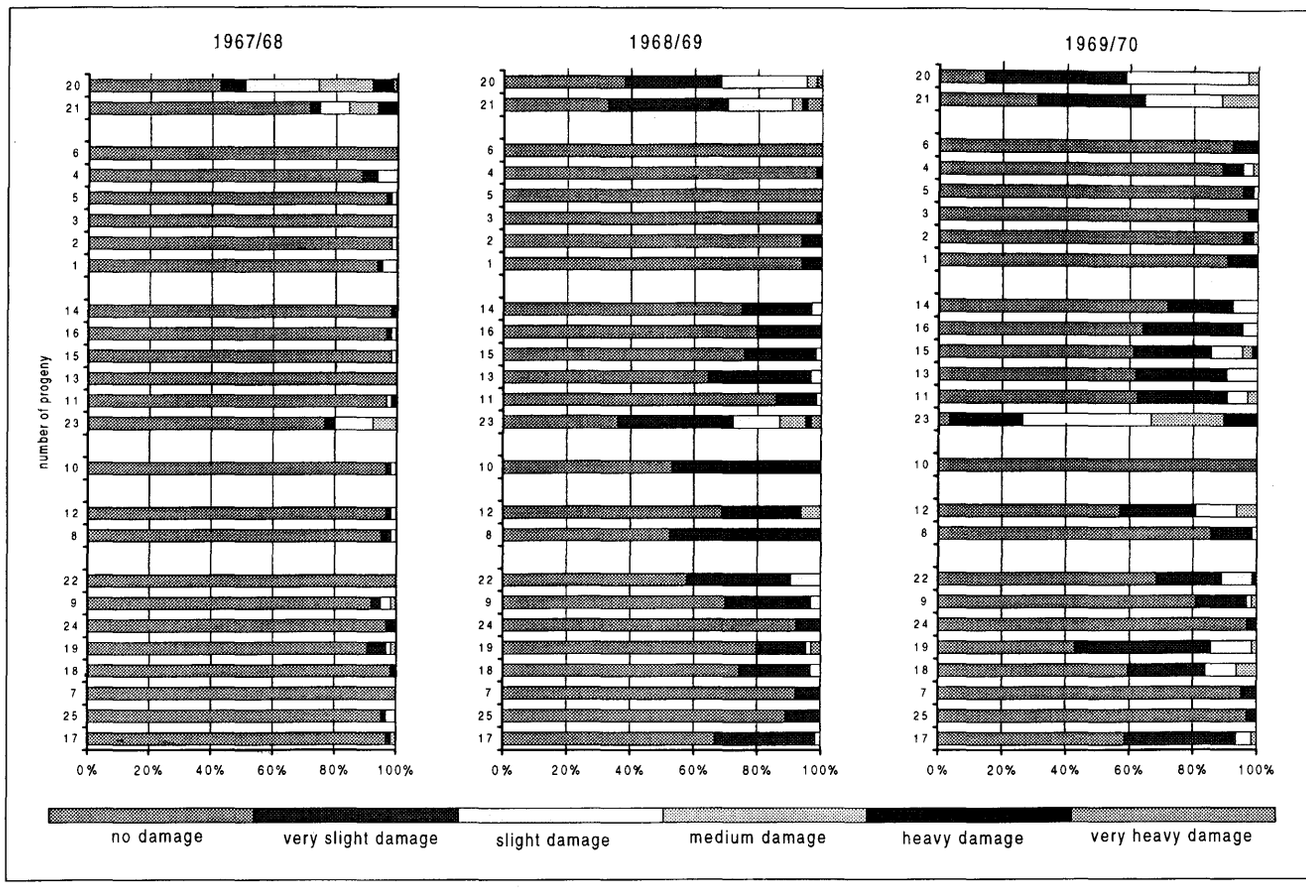

Fig.4. – Damage in the Douglas fir progenies by winter frost in the years 1967/1968, 1968/1969, and 1969/1970.

Table 4. – SPEARMAN's rank coefficients between various traits (winter frost, late frost, mortality) and geographical data compared on base of progeny means.

	latitude [°N] [1]	longitude [°W] [1]	altitude [m] [2]	mortality until age 7 (1969) [1]	age 8 (1970) [1]	age 10 (1972) [1]	age 23 (1985) [1]	age 32 (1994) [1]
winter frost:								
at age 6 (1967/68)	0.08 ns	0.17 ns	-0.23 ns	0.25 ns	0.24 ns	0.38 ns	0.18 ns	-0.03 ns
at age 7 (1968/69)	-0.55 **	-0.38 ns	0.55 **		0.74 ***	0.79 ***	0.52 **	0.37 ns
at age 8 (1969/70)	-0.57 **	-0.21 ns	0.41 *			0.46 ns	0.33 ns	0.12 ns
late frost:								
at age 6 (1968)	-0.63 ***	-0.26 ns	0.32 ns	0.29 ns	0.31 ns	0.39 ns	0.15 ns	-0.02 ns
at age 7 (1969)	-0.71 ***	-0.70 ***	0.70 ***		0.34 ns	0.34 ns	0.50 *	0.58 **
at age 8 (1970)	-0.71 ***	-0.76 ***	0.66 ***			0.36 ns	0.40 *	0.40 *

significances: *) ≤ 5% **) ≤ 1% ***) ≤ 0.1% ns = not significant
number of progenies: [1])n = 25 [2])n = 24

(no. 20), respectively. The development of the progenies from age 5 to 14 is shown in *figure 7.* Several groups of provenances can clearly be distinguished (see also chapter "Comparison of the Douglas fir progenies on base of all traits measured or assessed"): In all years the fastest growing progenies were the 2 seed lots from Oregon (no. 20, 21), followed by 6 progenies from Montana (no. 1 to 6) and 5 progenies from New Mexico (no. 11, 13 to 16). Slow growing progenies had their origin in Utah (no. 19, 22), Colorado (no. 8 to 10), and Idaho (no. 24). The ranking of the progenies was very similar during the years.

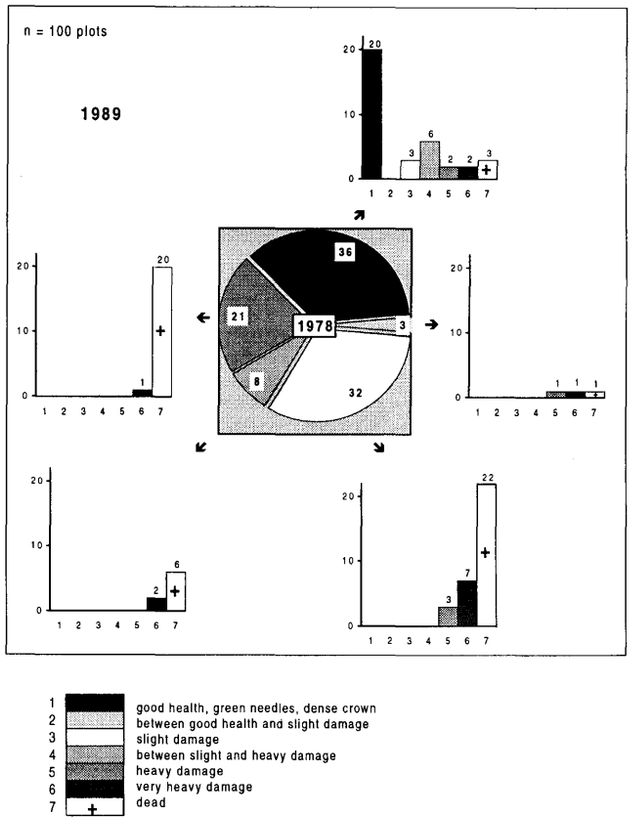

Fig. 5. – Condition of health as means of the Douglas fir progeny plots in 1978 (age 16) and the further development until 1989 (age 27).

Regarding the diameter growth similar results were observed. The largest mean diameter in breast height was calculated for the 2 progenies from Oregon with 16.5 cm, varying between trees from 4.5 cm to 34.5 cm.

Mean height and diameter at breast height in the various years were generally not correlated with the geographical latitude or longitude, and only to some extent weak significantly and negatively correlated with the altitude, which demonstrated that progenies from higher elevations were slow growing compared with progenies from lower elevations.

Volume production of Douglas fir and accompanying tree species

Until 1994 (age 32) the trial has not been thinned or cleared from naturally regenerated native tree species. Between still living Douglas firs and within plots where Douglas fir died, other tree species grew up. In autumn 1994 6 other tree species were identified and registered on the field trial area: 503 *Betula pendula* ROTH, 42 *Pinus sylvestris* L., 8 *Sorbus aucuparia* L., 3 *Salix aurita* L., 2 *Prunus serotina* EHRH., and 1 *Sambucus nigra* L., which all were higher than 1.3 m. It can be assumed that most of these trees are only little younger than the planted Douglas firs. The occurrence of these native species, their numbers within the plots of the respective Douglas fir progenies and the mean dbh values are listed in *table 5.*

The total volume production over bark per ha was calculated for all trees growing in the single plots including the naturally regenerated individual species. The highest volume (about 220 m^3/ha) was calculated on the base of plots with the progenies from Oregon (no. 20, 21). Douglas fir alone produced here more than 200 m^3/ha *(Fig. 8).* On base of plots with progenies from Montana (no. 1 to 6) there were totally between 125 m^3/ha and 183 m^3/ha with a Douglas fir portion between 98 m^3/ha and 176 m^3/ha. Plots with progenies from New Mexico (no. 11,

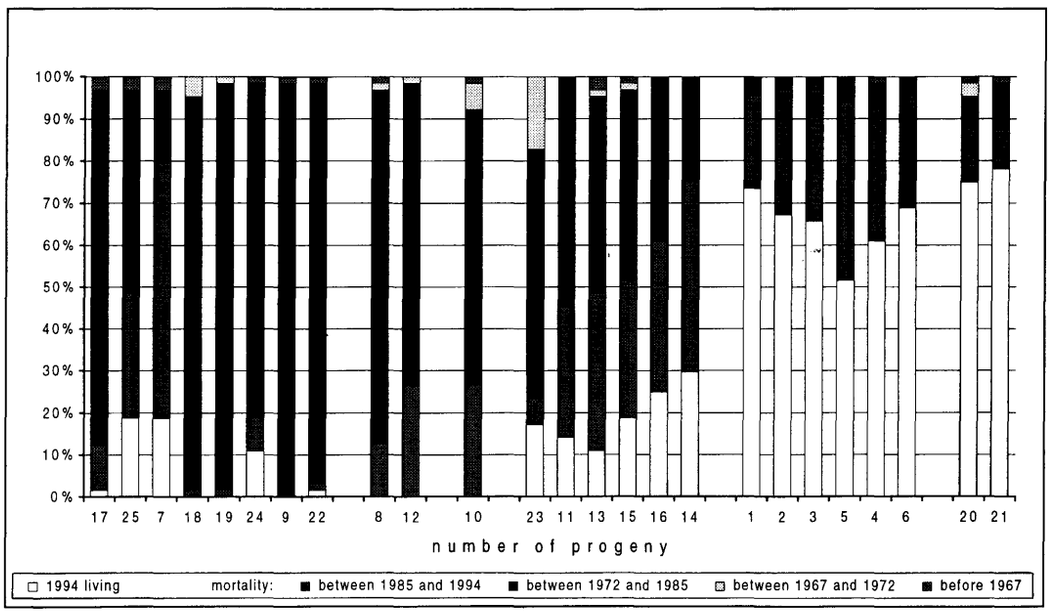

Fig. 6. – Mortality before 1967 (age 5) and until 1972 (age 10), 1985 (age 23), and 1994 (age 32), respectively.

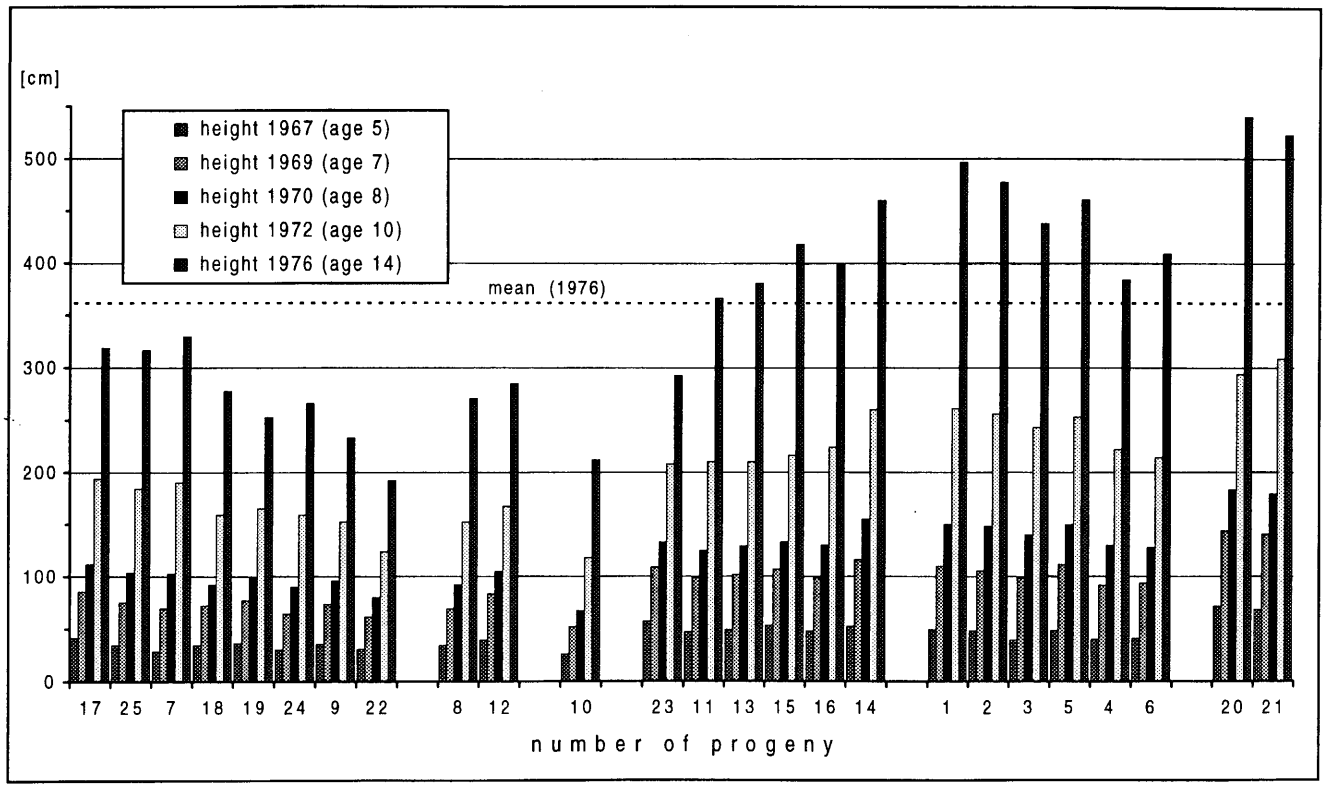

Fig. 7. – Height growth of Douglas fir progenies at age 5, 7, 8, 10, and 14.

13 to 16) and Mexico (no. 23) produced in total between 45 m^3/ha and 60 m^3/ha with a Douglas fir portion from 19 m^3/ha to 50 m^3/ha. In the plots of the other progenies the total volume was less than 70 m^3/ha and Douglas fir was missing or up to a third of the volume (*Fig. 8*).

Table 5. – Numbers and mean dbh of Douglas fir progenies and accompanying native tree species within the Douglas fir plots in autumn 1994.

progeny	*Pseudotsuga menziesii*	*Betula pendula*	*Pinus sylvestris*	*Sorbus aucuparia*	*Salix aurita*	*Prunus serotina*	*Sambucus nigra*	total
17 Arizona	1	17	1					19
25 Oregon	12	27				1		40
7 Montana	12	20						32
18 Arizona		24	6	2				32
19 Utah		33	1	1				35
24 Idaho	7	25						32
9 Colorado		31	4				1	36
22 Utah	1	29	1					31
8 Colorado		19	3	1				23
12 New Mexico		24	7					31
10 Colorado		18	5					23
23 Mexico	11	25	2		1			39
11 New Mexico	9	25	2	1				37
13 New Mexico	7	27	2					36
15 New Mexico	12	26		2				40
16 New Mexico	16	18	1		1	1		37
14 New Mexico	19	26						45
1 Montana	47	4						51
2 Montana	43	10			1			54
3 Montana	42	12						54
5 Montana	33	8		1				42
4 Montana	39	28	5					73
6 Montana	44	8						52
20 Oregon	48	14						62
21 Oregon	50	5	2					57
total	453	503	42	8	3	2	1	1012
dbh [cm]	12.6	9.8	13.6	7.6	15.5	12.9	12.5	11.2

Considering the single Douglas fir progenies as pure stands, then the volume production per ha corresponded for the Oregon progenies (no. 20 and 21) with the site index around II.6 of the Douglas fir yield table (SCHOBER, 1975) (*Fig. 9*). Three progenies from Montana (no. 1, 2, 4) were about site class III.0. All others were less than site class III.0. In comparision with local Scots pine, which has a site index between II.$1^1/_2$ (Ki [6]) and II.8 (Ki [5]), the 2 progenies from Oregon and 6 progenies from Montana produced more volume than Scots pine would have done on this site. Two progenies from New Mexico (no. 14, 16) have a volume production comparable with Scots pine on this site. The other progenies produced less volume or died completely.

Discussion

Douglas fir has a very large natural distribution area in western North America with different climatic and edaphic conditions. After the Wisconsin glaciation this tree species migrated obviously from 2 refugia into the present area. Its great variation is therefore not surprising, if one considers the large natural range. Taxonomically 2 varieties are distinguished: *P. menziesii* var. *menziesii* along the coast, and *P. menziesii* var. *glauca* in the interior. The latter variety is often separated additionally into a grey form of the northern interior, and a blue form of the southern interior. There exist numerous transition forms between all Douglas fir forms mentioned, especially in the area between the so-called grey form and the green coastal form, e.g. in western Montana, northern Idaho and north-central Washington (CHING and HERMANN, 1973). Recent studies showed that on the base of chemotaxonomic characteristics 4 chemical races can be differentiated (for details see the review by HERMANN, 1981), which in part agree with the botanical varieties. On base of this distinction the 25 progenies of the present study can correspond with the following groups:

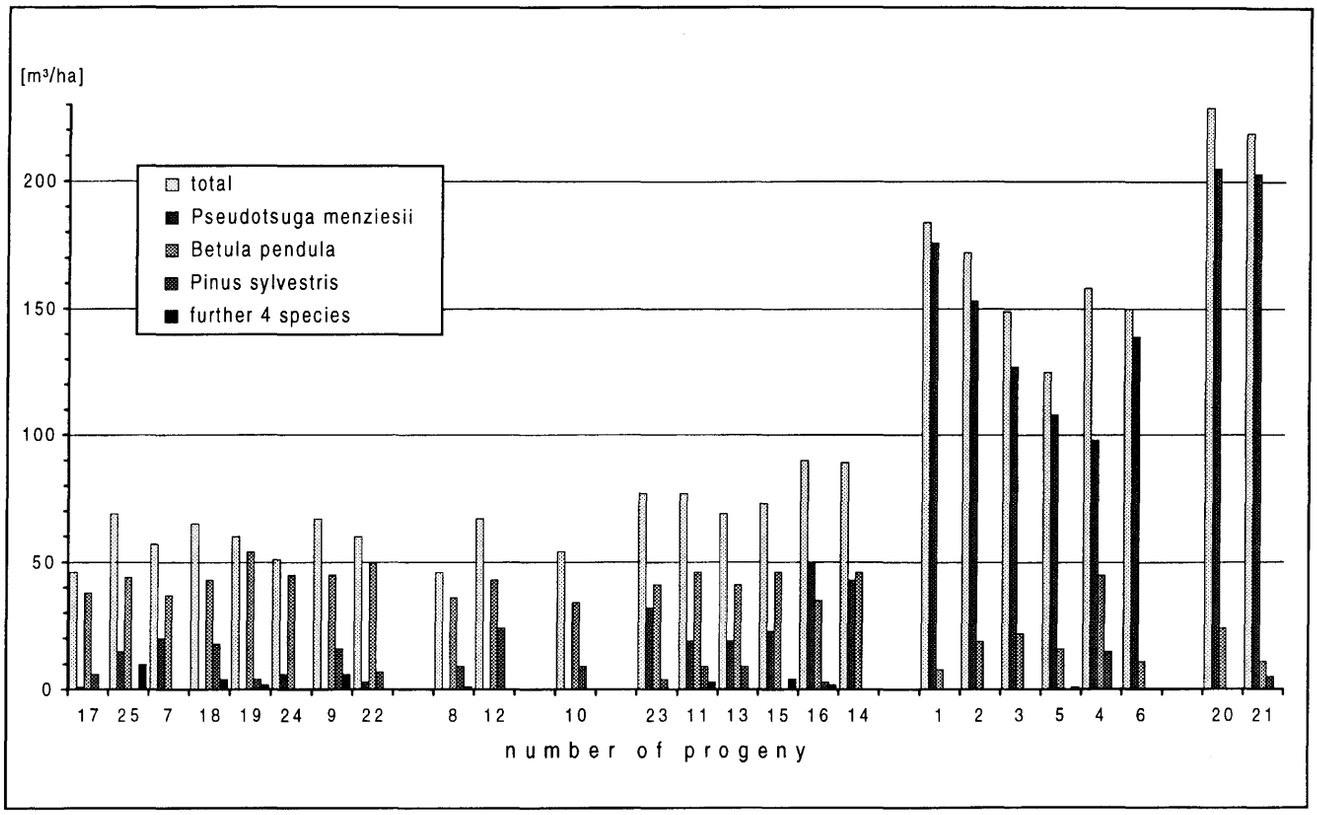

Fig. 8. – Volume over bark per ha in 1994 (total and separate for the individual species) in the 29 year old trial. Douglas fir was planted in 1966 with 3 year old seedlings, other tree species regenerated naturally.

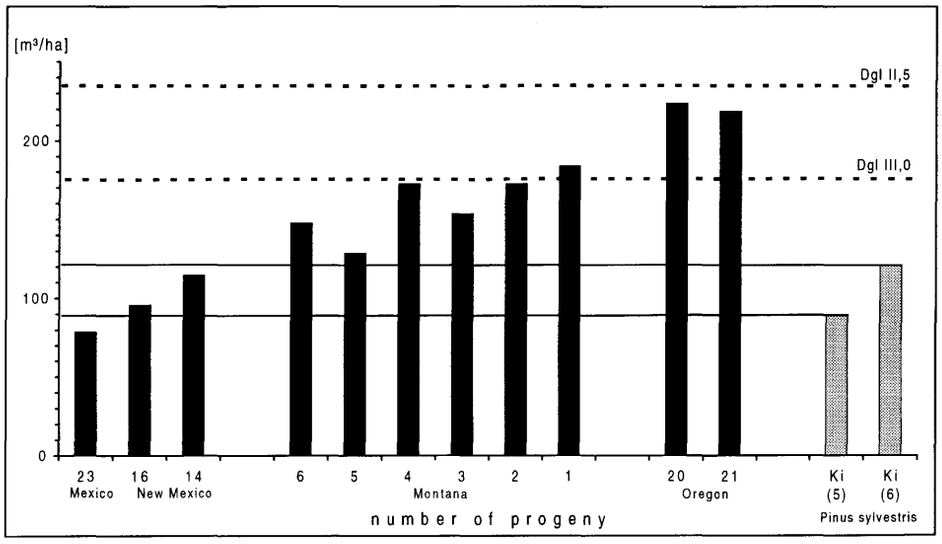

Fig. 9. – Volume over bark per ha calculated for pure stands of 11 selected Douglas fir progenies in comparison with yield tables for Douglas fir and Scots pine.

Group A: western Oregon (no. 20 and 21).

Group B: Montana (no. 1 to 7). Progeny no. 7 can probably already belong to group C. Transition group A/B: eastern Oregon (no. 25) and probably southwestern Idaho (no. 24).

Group C: southern interior: Utah, Colorado, Arizona, New Mexico and Mexico.

In the test progenies of the group D and the transition group A/D are missing. There is partly a good agreement between this grouping and the main groups of the dendrogram (*Fig. 2*).

Douglas fir populations within the chemical races correspond in the composition of terpene substances. These types agree again with other traits, e.g. with resistance or susceptibility to some biotic agents. One can state that Douglas fir populations of the chemical race A are highly resistant to *Rhabdocline pseudotsugae*, but very susceptible for the infestation by the woolly aphid (*Gilletteella cooleyi* GILL.), populations of race C are highly susceptible for the needle cast disease shown also by results of the present study, but are very resistant to the woolly

aphid, and populations of race B together with the transition forms behave differently (STEPHAN, 1987).

The great variation of various traits within provenances of Douglas fir is known since long (KANZOW, 1936; SCHOBER, 1954). Regarding the attack by *Rhabdocline pseudotsugae* one can find for instance individual healthy trees within otherwise severely attacked progenies, e.g. from New Mexico or Colorado, confirming the high variability also in resistance traits (STEPHAN, 1973b, 1980). This trial was established with seed mostly from open-pollinated single trees which can explain some of the variation between progenies from adjacent regions, but it does not represent the whole variation of provenances of the respective region.

The field trial does unfortunately not contain Douglas fir progenies from areas known for their good growth and quality in Germany. Only the 2 western Oregon progenies (no. 20 and 21) originate from seed zone 262, which is adjacent to seed zones, from where seed import is recommended. Douglas fir provenances from these seed zones are for instance present in the large IUFRO seed collection of 1966/1968 and are growing well under central European conditions (see the summarizing review of KLEINSCHMIT and BASTIEN, 1992). Therefore, one can compare the other progenies of the trial with these 2, and find that the Douglas firs from Montana, which were in the past very rarely used in provenance trials, are vital, less susceptible to *Rhabdocline* (*Fig. 3*), and seem to be better adapted to the environmental conditions of the test site in Northwest Germany than other progenies, although their growth performance and volume production was relatively low, so far.

In this connection also the behaviour of progenies from New Mexico is interesting. Although they belong to the generally for central Europe unsuited blue variety or the chemical race C, respectively, some of them were attacked less by *Rhabdocline* needle cast than for instance progenies from Utah or Arizona (*Fig. 3*). Also MERRILL et al. (1990), working with a different collection of seed in eastern North America, found that trees originating from New Mexico seed were more resistant. The Mexican progeny (no. 23) showed no real difference in its behaviour with New Mexican progenies, but it could not yet clarified, whether it belongs to *P. menziesii* var. *glauca* or to *Pseudotsuga macrocarpa* (VASEY) MAYR, a species native in southwestern North America.

In relation to the reaction of the Douglas fir progenies to winter frost the results show a higher resistance in progenies from the continental part of North America and from higher altitudes, which corresponds with results of other authors (e.g. KANZOW, 1936; SCHOBER and MEYER, 1955; SCHOBER, 1963). The results about the late frost reaction gives no clear picture stated also by others (e.g. KANZOW, 1936; STERN et al., 1974; HATTEMER and KÖNIG, 1975). In general, Douglas firs from the interior flush earlier than the coastal form, and it is therefore more likely that they suffer by late frost.

The progeny test plantation, still unmanaged until the age of 32 years, demonstrates very interestingly that the progenies from Oregon and Montana can compete with local, naturally regenerated tree species and can therefore be considered as more or less adapted to this site. The relatively low volume production is probably caused by both the competition within the plots and the *Rhabdocline* needle cast, which significantly reduces the height growth, radial increment and timber production of affected trees (KURKELA, 1981; KÜCHEMANN, 1993).

Summarizing it can be stated that, in general, the results with these open-pollinated single tree progenies correspond very well with results of other provenance trials as far as provenances of similar origin of the natural range were used. New are the more detailed informations about the behaviour of Douglas fir from Montana. It seems worth-while to examine provenances or progenies of that region on more sites for proving their suitability for special locations.

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