INTERPROVENANCE BREEDING IN SCOTS PINE[1]/

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Abstract.--In a breeding program begun in 1970, 7 select tester trees are being used to produce progenies for evaluating 43 Scots pine seed orchard selections of provenance origin and to provide material for recurrent selection. Average cone survival has been 50 percent (range 36 to 60) and number of sound seeds per cone 6 (range 3 to 12) over a 5-year period. Preliminary analyses indicate 76 and 58 percent of the total variation for cone survival and number of seed per cone, respectively, is attributable to the ovulate parents. General combining ability (GCA) effects appear larger than specific combining ability (SCA) effects among testers. GCA effects were not different except for one tester in cone survival. SCA effects indicate wide variability. Data suggest sufficient variation in cone survival and seed per cone for effective selection; and importance of choosing specific combinations of parents.

Additional keywords: Scots pine, *Pinus sylvestris*, breeding program, tester-cross, cone and seed production.

In theory, the genetic evaluation of clonal seed orchard selections, through breeding and progeny testing, should precede the establishment of the seed orchard. In practice, however, progeny testing of the selected parent trees is commonly delayed until ramets of the selected ortets produce ovulate strobili in the seed orchard. This is due, primarily, to the expense, difficulty, and inconvenience of breeding large, widely separated parent trees under field conditions.

In the present program we initiated our breeding program concurrently with the establishment of a production seed orchard (Van Haverbeke, Bagley and Benson 1973, Van Haverbeke 1974).

THE BASE POPULATION

In 1958 a regional effort was begun to improve the quality of Scots pine (*Pinus sylvestris* L.) planting stock throughout the northcentral region of the United States (Wright and Bull 1963, Wright et al. 1966). In 1962 personnel of the Rocky Mountain Forest and Range Experiment Station, U.S.D.A. Forest Service, and the Department of Horticulture and Forestry, University of Nebraska -- in cooperation with Wright -- established a Scots pine provenance test plantation near Plattsmouth, Nebraska, containing over 1,000 seedlings from 36 stand origins across Europe and Asia (Read 1971).

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THE BREEDING POPULATION

In 1970, when the provenance plantation was 8 years old, each tree was rated for foliage color, balance, foliage density, form, taper, needle retention, and stem straightness -- all desirable Christmas and ornamental tree characteristics. Forty-three superior phenotypes were selected as the breeding population for the development of an improved strain of Scots pine.

Because winter foliage color is an important Christmas and ornamental tree characteristic, most of our superior selections came from provenances in the southern portion of the species range: from provenances 218, 245, 240, 239, 235, 203, 557, 556, 554, 242, 551, 243, 220, 261, and 264 (Read 1971)-- sources noted for their green to blue-green winter foliage color. Provenances 235, 230, 557, 556, and 554, however, do not develop this desirable winter foliage color in Michigan or Pennsylvania.3/ Eighteen of the 36 provenances are represented among the selections. Numbers of selections per provenance ranged from one to six.

The provenance test trees were the same age, growing under relatively uniform spacing and site conditions; the origins were randomly assigned within the plantation to permit valid analysis of their performances.

We initiated a full-sib progeny test by making controlled matings among the selected trees in the provenance test because: (1) the selected trees were concentrated in one convenient location, (2) the ease of making controlled crosses on trees 8 years of age, and (3) several selected trees were producing strobili. We reasoned that several years could be gained by making controlled pollinations on the parent trees, rather than waiting for ramets in a grafted seed orchard to produce strobili.

Also, the relatively uniform environment of the test site made it likely that the phenotypic expressions of the selected trees' characteristics were a fairly accurate manifestation of their genotypic potential. For these reasons we also decided to establish a clonal seed orchard of the selections concurrently with the initiation of the breeding program.

BREEDING SCHEME

The North Carolina State Design II (Tester-Cross) was adopted in our program to determine the genetic value of the selected trees. This breeding scheme is considered to be one of the simplest and most flexible programs for testing progeny from controlled pollinations (Zobel et al. 1972). It provides information about general combining ability (GCA), gives a measure of specific combining ability (SCA), and can give information on inbreeding effects. This scheme requires the use of four to six of the select trees, designated as testers, which are crossed with all of the select trees.

3/ Gerhold, Henry D. personal communication.

This scheme yields a satisfactory estimate of parental breeding value, but has been criticized for use in relatively small programs because the progeny population produced for recurrent selection is restricted by too few unrelated families (Zobel et al. 1972). There can be no more unrelated crosses than the number of testers used. However, in view of the extreme genetic diversity of our breeding material, and limited pollen production on our relatively young select trees, we concluded it was best suited for our program.

Seven of the select trees which produced abundant pollen, and represented germ plasm from six provenances across an east-west transect of the species range (number 239, 556, 557, 242, 243 and 264) were selected as the testers.

We used the "Mini Bag" technique (Gerhold 1968) and plastic bottle pollinators (Barnhart 1976) for making our controlled pollinations.

We realized our superior trees were quite young when selected. Thus, the presence and quantity of strobili were limiting factors early in the program--precluding initiation of a breeding scheme such as one of the diallel plans. About 10 of the selected trees have yet to produce any, or enough, strobili, including one of the tester trees, to warrant breeding them. Since one of our major objectives was the establishment of a production seed orchard as quickly as possible, we may have to eliminate the trees selected originally that are still infertile, and replace them in the breeding program with fertile trees that were less desirable in the original selection process.

RESULTS AND DISCUSSION

Strobili Production

The number of select trees producing ovulate strobili has increased from 23 to 33 during the past 7 years, with indications that additional trees will be producing ovulate strobili, and pollen, as they continue to mature (Table 1).

Cone Survival

Cone survival during the past 5 years has averaged 50 percent, with a range of 35 to 60 percent (Table 1). Brown (1971) reported 65 percent cone survival in England with fresh pollen, as we also use, but only 30 to 65 percent survival with stored pollen. We have not investigated the causes of our cone losses, but believe many are lost during the first year between pollination and fertilization. Brown (1971) stated that final cone and seed yields from control-pollinated crosses may be influenced by breakdown of any one of the processes of pollination (pollen grain germination, pollen tube growth), fertilization, embryo development, or premature abscission of maturing cones.

Seed Yields

We have attained averages of about 6 and 4 seeds per cone in control- and open-pollinated cones, respectively (Table 1). Yields from our controlled pollinations , in terms of sound seed per cone, have not been impressive, but have been similar in magnitude to yields reported by Johnson et al. (1953)

Table 1.--Ovulate and staminate parents, matins, cones pollinated and harvested, cone survival, sound seed, and seed per cone in Scots pine interprovenance breeding program.

				Control-pollinated					Open-pollinated		
Year (spring)	Ovulate trees	Staminate trees	Matings	Cones pollinated	Cones harvested	Cone survival	Sound seeds	Seeds /cone	Cones harvested	Sound seeds	Seeds /cone
	Number			Number		Percent	Number		Number		
1970	23	3	55	348	185	53.2	522	2.8	--	--	--
1971	29	6	146	1355	471	34.8	1412	3.0	115	153	1.3
1972	32	7	168	1820	1096	60.2	12911	11.8	2154	18209	8.5
1973	32	6	146	1593	858	53.9	4097	4.8	2233	10643	4.8
1974	32	7	216	2707	1295	47.8	3749	2.9	4890	10731	2.2
1975	32	7	160	2582	--	--	--	--	--	--	--
1976	33	7	125	2387	--	--	--	--	--	--	--
1977											
Total			1016	7823	3905		22691		9392	39736	
Average						49.9		5.8			4.2

and Brown (1971). Gerhold has obtained average yields of 10 to 14 seeds per cone in different years on the same Scots pine trees cross-pollinated in. Michigan.3/

Our cones are processed and seed extracted as described by Van Haverbeke (in press).

Insects and Disease

Average seed yields per cone rose from about 3 in 1971 to nearly 12 in. 1973, then decreased sharply to about 3 by 1975 (Table 1). We believe this decrease was largely attributable to a dramatic build-up of the leaf footed pine seedbug (Leptoglossus corculus)(Say) (Ebel et al. 1975). This sucking insect feeds upon the developing pine cones. It moves from cone cluster to cone cluster, puncturing the cone scales with needle-like mouthparts, and extracting nutrients from individual seeds.

The selected trees were treated in spring 1976 with the granular form of the systemic insecticide carbofuran (common name; Furadan, trade name 10% (10G) at rates of 170 and 227 gm. per inch of stem diameter at breast height. The granules were raked into the soil out to the drip-line of the tree crowns. Results will be evaluated in fall 1976.

Skilling and Nicholls (1974) reported serious losses of Scots pine by Christmas tree growers in the north central states due to brown spot needle disease, caused by the fungus Scirrhia acicola (Dearn.) Siggers. They reported that the short-needled varieties of "Spanish" and "French green" Scots pine are more susceptible to the disease than the long-needled varieties. We have detected brown spot on one of our select trees- a short-needled tree of Spanish origin from source 245.

Genetic Trends

Cone and seed data from this breeding program can not yet be directly tested for significance because of lack of a proper error term (no replication of select trees as in a clonal seed orchard, and incomplete repetition of all crosses in all years). While these data must be considered preliminary and viewed with caution (Schrum et al. 1975), some genetic trends are apparent. The ovulate (female) parents accounted for 76 and 58 percent of the total variation in percent cone survival and number of sound seeds per cone, respectively. Only 0.7 and 6 percent of the variation for these characters was attributed to the staminate (male) parents. This is not surprising since both characters are primarily maternal functions, especially cone survival. Karrfalt and Gerhold (1973) and Karrfalt et al. (1975) found that the number of filled seeds per cone, as well as seed weight, was influenced by both parents, but was affected to a much larger extent by the ovulate parent.

Ovulate trees appear to differ widely in their inherent ability to carry cones to maturity and to produce viable seed (Tables 2 and 3). Brown (1971) also reported that cone losses varied greatly among clones even when one pollen source and one isolation procedure were used. He and Forshell (1974) further reported that the total number of seeds per cone was specific to each "mother" clone in Scots pine and varied greatly among clones. Although the

Table 2.--Ranking of select Scots pine trees on basis of combined performances of mean percent cone survival and number of sound seeds per cone. (r = 0.481).

Select tree	Mean percent cone survival	Mean seeds per cone
L-261-3	84.4	13.0
G-265-2	82.3	10.4
I-203-1	48.5	15.1
M-220-4	52.7	10.6
G-261-2	81.7	8.0
F-242-4	75.8	6.5
G-243-4	74.1	7.5
G-242-1	76.7	3.0
N-240-4	75.6	0.8
G-556-1*	66.1	7.0
G-245-1	65.9	4.3
L-242-1*	64.6	5.2
E-239-2*	62.1	6.8
E-261-3	59.7	5.6
I-243-1*	60.0	5.1
J-264-1*	61.3	2.7
B-554-4	54.9	5.5
L-527-4	53.4	5.5
I-240-4	55.0	3.8
B-220-3	49.6	6.2
K-203-2	46.3	6.8
D-235-4	38.8	5.5
G-242-3	38.5	2.6
G-557-1*	32.0	9.0
F-264-1	33.9	4.9
I-240-1	34.0	0.2
L-218-3	33.4	0.7
B-527-3	26.6	3.5
F-554-4	25.7	2.5
A-240-4	23.2	0.4
D-318-3	19.1	2.8
K-239-1	14.4	3.6

* Select trees used as tester (pollen)parents.

Table 3.--Mean values of percent cone survival and number of seeds per cone among tester crosses.

Ovulate (female) testers	Staminate (male) testers E 239 2	L 242 1	I 243 1	J 264 1	G 556 1	G 557 1	Totals
E-239-2	-	63.5	69.5	74.2	59.7	43.8	310.7
	-	(6.0)	(8.8)	(9.5)	(5.2)	(4.4)	(33.9)
L-242-1	77.3 1/	-	58.8	75.6	42.3	69.0	323.0
	(4.6)	-	(6.9)	(8.2)	(3.9)	(2.4)	(26.0)
I-243-1	55.0	52.9	-	68.0	71.4	52.6	299.9
	(3.5)	(3.7)	-	(6.8)	(4.0)	(7.6)	(25.6)
J-264-1	30.0	60.0	66.7	-	66.7	83.3	306.7
	(2.0)	(2.7)	(5.0)	-	(2.0)	(2.0)	(13.7)
G-556-1	75.3	54.1	85.7	46.9	-	68.5	330.5
	(2.8)	(7.4)	(10.4)	(6.7)	-	(7.8)	(35.1)
G-557-1	41.4	28.9	16.3	31.6	41.8	-	160.0
	(2.8)	(9.1)	(12.0)	(16.2)	(4.8)	-	(44.9)

1/ First value shown is for percent cone survival; value in parenthesis is for number of sound seeds per cone.

specific reasons for this variation, detected also in this study, are not fully identified, it can very probably be attributed first to the inherent ability of particular genotypes to produce cones and seed, and second, to the interaction of these extremely diverse genotypes with the local environment. Variation may also be due to susceptibility of ovulate parents to seedbugs. The two characters investigated in this study--percent cone survival and number of sound seeds per cone--showed a low correlation (0.481).

Contrary to the findings of Brown (1971), our control-pollinated cones are yielding slightly more seed per cone than open-pollinated cones from the same trees. This could be attributed to inadequate pollen production from so few trees, or such diverse origins, in a non-indigenous environment.

While our seed yields seem low, they are the residual seeds left after flotation in petroleum ether (Krugman and Jenkinson 1975). A germination test of three lots of control- and open-pollinated seed yielded percentages of 92 (L-261-3 x 1-243-1), 92 (B-554-4, O.P.) and 79 (E-556-2, O.P.). These data suggest that sound seeds were extracted (Table 4).

Estimates of combining ability are traditionally derived from progeny performances rather than parental performances as we have done. There is genetic variation in cone survival and seed production however, and estimates were computed to further interpret genetic effects. Estimates based on the performances of progenies derived from these crosses will be made. at an appropriate time in the future.

Among the tester trees, general combining ability (GCA) effects appear to be somewhat larger than specific combining ability (SCA) effects for both variables. GCA effects do not appear to be greatly different among testers except for poor cone survival for tree G-557-1 (Table 5) (Griffing 1956).

Estimates of SCA effects, however, show wide variability among the trees for percent cone survival, but are relatively uniform for number of seeds per cone (Table 5). This probably indicates that certain pairings are more compatible than others.

Estimates among the tester trees suggest that reciprocal effects are large, especially with regard to cone survival, in crosses involving G-557-1 (Table 6) (Griffing 1956). This indicates that the reciprocal crosses are not performing similarly; perhaps care should be taken in the choice of seed parent for particular crosses.

Our select trees were released from competitive influences by removal of adjacent trees on all sides. However, some crowding--leading to shading of branches, loss of vigor, and ultimate loss of cones--could have influenced cone survival in certain portions or sides of the crowns. While the spatial arrangement of the various matings within the crowns was presumed to be random, crowding effects could explain, in part, the large reciprocal effects shown in Table 6. Brown (1971), for example, found cone drop on the north side of the crowns of Scots pine was almost double the drop on the south side.

Table 4.--Sound control-pollinated seeds produced in Scots pine interprovenance breeding program after 5 harvests (1971-1975).

Ovulate:	Tester parents						
parents:	E	L	I	J	G	G	M
:	239	242	243	264	556	557	557
:	2	1	1	1	1	1	2
G-265-2	206	249	231	254	195	246	145
D-318-3	46	16	24	15	6	43	9
L-218-3	7	9	4	1	20	13	0
G-245-1	104	100	5	43	67	10	48
A-240-4	9	7	1	19	1	1	0
I-240-1	9	4	0	0	0	0	1
I-240-4	59	71	62	32	122	107	59
N-240-4	30	45	57	49	32	47	5
E-239-2	-	281	343	435	207	123	76
K-239-1	8	16	68	48	41	24	0
D-235-4	107	63	95	120	38	110	47
I-203-2	33	90	190	211	322	339	90
K-203-2	14	112	53	137	83	67	40
B-527-3	64	51	0	24	72	22	24
L-527-4	272	90	139	110	63	86	68
B-554-4	104	317	286	198	102	278	108
F-554-4	59	30	14	21	129	28	3
G-556-1	160	149	250	101	-	290	117
G-557-1	68	100	84	195	111	-	44
F-242-4	54	55	31	74	11	39	118
G-242-1	43	29	36	14	35	2	16
G-242-3	60	27	60	13	42	39	7
L-242-1	155	-	138	255	43	70	43
B-551-3	10	3	-	-	-	-	-
G-243-4	96	275	325	7	353	111	85
I-243-1	76	67	-	115	9	45	54
B-220-3	103	99	174	132	128	142	89
M-220-4	35	165	185	143	330	230	11
E-261-3	74	41	221	76	25	27	24
G-261-2	323	184	268	446	184	234	166
L-261-3	515	366	657	610	348	176	304
F-264-1	147	40	156	55	89	6	6
J-264-1	6	16	30	-	3	10	7

Table 5.--Estimates of general and specific combining ability effects for cone survival and seeds per cone in select Scots pine tester trees.

Select ovulate trees	GCA 1/	SCA 1/				
		E-239-2	L-242-1	I-243-1	J-264-1	G-556-1
E-239-2	1.596 2/ (-1.267)					
L-242-1	0.683 (-0.604)	10.428 (1.198)				
I-243-1	2.496 (1.121)	0.465 (0.322)	-5.022 (-1.190)			
J-264-1	3.258 (0.171)	-10.448 (0.872)	6.165 (-0.090)	3.902 (-1.365)		
G-556-1	4.433 (-0.592)	3.778 (-0.115)	-14.610 (0.872)	13.928 (0.698)	-8.585 (-1.202)	
G-557-1	-12.467 (1.171)	-4.222 (-2.278)	3.040 (-0.790)	-13.272 (1.535)	8.965 (1.785)	5.490 (-0.252)

1/ GCA = general combining ability; SCA = specific combining ability

2/ First value shown is for percent cone survival; value in parenthesis is for number of sound seeds per cone.

Table 6.--Estimates of reciprocal effects among testers for cone survival and seed per cone.

Select ovulate trees	Tester trees				
	E-239-2	L-242-1	I-243-1	J-264-1	G-556-1
L-242-1	-6.900 1/ (0.700)				
I-243-1	7.250 (2.650)	2.950 (1.600)			
J-264-1	22.100 (3.750)	7.800 (2.750)	0.650 (0.900)		
G-556-1	-7.800 (1.200)	-5.900 (-1.750)	-7.150 (-3.200)	9.900 (-2.350)	
G-557-1	1.200 (0.800)	20.050 (-3.350)	18.150 (-2.200)	25.850 (-7.100)	13.350 (1.500)

1/ First value shown is for percent cone survival; value in parenthesis is for number of sound seeds per cone.

These data indicate the importance of choosing the specific parents in a combination, and then the selection of which of those parents to use as the female to attain maximum cone survival. For example, note crosses of G-556-1 to L-242-1 and 1-243-1 for specific and reciprocal effects. These data also suggest genetic variation among the sources is sufficient for selection to show progress, especially with respect to cone survival. Less variation exists for number of seeds per cone, but the range in values indicates that some progress could also be made.

CONTINUING PLANS

Our goals include: (1) evaluation of the select trees through progeny testing, (2) recurrent selection from within these progenies, and (3) their conversion to either an improved seedling seed orchard or the establishment of a second production clonal seed orchard. Zeaser (1976) detected desirable combinations of traits (height, winter foliage color, needle length, crook and sweep) in family progenies from inter- and intra-varietal Scots pine matings.

We anticipated completing a substantial number of the required matings by spring 1976 and initiating a progeny test with as many of the trees as we have complete sets of crosses in spring 1978. We expect this number to include about 25 to 30 trees, or 197 to 210 separate progeny families.

Realizing that our program is not large and that the tester-cross program yields a relatively small number of unrelated families, we made about a dozen single-pair matings in spring 1976, utilizing combinations of parents not heretofore combined, and some new selections. These crosses will be included in the above progeny test to provide additional variation for recurrent selection.

A second progeny test will follow which will include the remaining select trees not yet producing strobili, and those for which complete sets of crosses are not yet finished.

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