GROWTH RATES OF EIGHTY SCOTCH PINE POPULATIONS AT FOURTEEN YEARS IN MARYLAND

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INTRODUCTION

Scotch pine (*Pinus sylvestris* L.) grows in a large range in Europe and the northern regions of Asia, and is adapted to diverse physiographic and climatic conditions. In the Caucasus, it is found at elevations of 8,500 feet, while in the Baltic states it grows near sea-level; in southern Europe, the species enjoys a mild climate, while in Siberia it is adapted to long and cold winters. Growing in these and other diverse environments, Scotch pine has evolved into a number of varieties and geographic strains. Selection of the best genetic strains for seed collection and for planting in Europe and elsewhere is very important from the economic stand point.

In the United States, Scotch pine is the most planted pine for Christmas trees. It has attractive foliage, dense and well-shaped branching and is adapted for planting on a variety of soil sites. Some selected strains of Scotch pine could be planted for timber, especially on some soil poor sites where other commercial trees cannot be planted, For instance, Scotch pine may be a good substitute for planting on shallow and dry soil sites in the Appalachian Region, where eastern white pine (P. strobus) fails.

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Historically, Scotch pine was one of the first pines planted in experimental plots for studies of its racial variation, and one of the first goals was to select the most desirable seed sources for production of shipmasts (De Vilmorin, 1862). Many other research plantations were established and studied to select strains with best growth rate and other characteristics (Kalela, 1937; Langlet, 1936; Schreiner et al. 1962, Wright and Balwin, 1957). These and other studies gave much information on the values of different strains for Christmas trees (Wright et al. 1966; Genys, 1970; King, 1965), Some results were based on measurements of young trees, and questions were raised concerning validity of the data for predicting the growth rates of trees in their advanced ages. In Maryland, eighty populations of Scotch pine were studied when they were 2,2 to 8.4 feet tall, and currently the same strains were measured and compared when they ranged in height from 10.6 to 25.9 feet. In the first instance, the data were valuable for selection of seed sources for Christmas trees, while this current information on older trees may help in selection of promising seed sources for production of timber.

METHODS

Scotch pine seedlings for this study were produced by Dr. J. W. Wright in East Lansing, Michigan, and details on their origin and nursery management were reported by Wright and Bull, 1963. In April 1962, 3-year-old seedlings, representing about 80 provenances, were brought back from Michigan, and planted in two locations of Maryland, one site in the Piedmont Plateau and the other in the Allegheny Region.

This report is based on a plantation that was established in Maryland's Piedmont Plateau, near the Liberty Lake in Carroll County, at an elevation of 450 feet. The site is a former farmland, somewhat rolling and slightly exposed to the south. Originally, this experiment included 81 populations, arranged in five balanced lattice squares. Two strains, after a high mortality, were replaced, and the population No. 221 was represented twice. Individual plots consisted of rectangular squares of four trees, spaced at 7' x 7'. The first measurements in this plantation were made in Winter 1965, and a report with experimental details was published by Genys in 1970. The measurements for the present information were made in the spring of 1974 when the trees were 14 years old from seed. For the analysis of data, plot means were used as items. One analysis of variance was conducted considering that the experiment was arranged in five randomized blocks; the second analysis was based on the experimental design of five balanced lattice squares as described by Cochran and Cox, 1950. Details of these analyses, and comparison of the efficiency of the two experimental designs are given below.

RESULTS

Data on the origin of the populations studied, their mortality rates, and their heights at 8 and 14 years are listed in Table 1. The relationships among different characteristics, including the foliage color and leaf-lengths as determined in previous studies, are given in Table 2. A special chapter is devoted to the discussion of the efficiency of the balanced lattice squares design.

Variation in Mortality.--During the first four years after planting, 12 percent of the trees died. Very high mortality, more than 50 percent, occurred in one population from northern Finland and in four populations from France. Two populations (Nos. 229 and 240) were replanted by other sources (Nos, 276R and 221R), Also, in 1964, all missing trees within plots were replanted with stock of the same source.

During the following seven years, again 12 percent of all trees died, and the differences in mortality rates among some different populations were statistically significant (Table 1). This time again, much mortality occurred among the same populations, and the mortality rates for both periods were moderately correlated (r=,55), The highest mortality rates were among the populations originating from the outlayers of the species range, such as varieties lapponica, uralensis, altaica, and aquitana. In some varieties, the mortality rates varied among different populations. For instance, within variety septentrionalis mortality rates varied from 5 to 40 percent. Also, in some instances, mortality rates varied among the populations originating from different trees in the same stand.

Almost all populations of varieties hercynica and haguensis showed excellent survival. In general, the populations that showed an excellent survival, also had outstanding heights; these two characteristics were moderately correlated (r=.50). Otherwise, the mortality rates were not related to either the geographic factors, such as latitude, longitude and elevation, or the foliage characteristics, such as needle length or needle color.

Heights.--At 14 years of age, the plantation mean-height was 21.0 feet, and heights of different populations ranged from 10.6 feet to 25.9 feet (Table 2). The slowest growing trees originated from northern Finland; the fastest growing - from a plantation in Achel, Belgium. In comparison to the population mean (=100%), the range of variation extended from 50 to 123 percent, Apparently, the fastest growing population was 2.5 times taller than the slowest-growing.

Table 1 indicates that all populations belonging to the varieties septentrionalis, uralensis, mongolica, and aquitana were smaller than the plantation mean; and varieties haguensis, borussica, hercynica and polonica were larger. Varieties scotica, rigensis and iberica grew at an average rate.

A strong intra-varietal variation was found within var. septentrionalis, and especially among the populations from different latitudes in Sweden and Norway. The experiment included five sets of populations from different mother trees in the same stand. The first set of four populations from Eksismoen, Norway, showed a very distinct variation in their heights; the two series of populations from Germany (Gustrow and Neustrelitz) were relatively uniform; and the two sets of populations from Belgium plantations (Achel and Hechtel) were moderately variable.

The growth rates of 14 year old trees were strongly correlated with their growth rates at eight years (r=.81), and with the heights in Michigan and in western Maryland (Table 2). Selection of the best

Table 1.--Data on origin, mortality and growth rates of different progenies of Scotch pine (*Pinus sylvestris*) studied in Piedmont Plateau of Central Maryland.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Origin of seedlots				Mortality		Height	
Variety, region	MSFG seed lot number	North latitude	East longitude	Elevation	in 4 yrs	after restoration	at 8 yrs	at 14 yrs
		- degrees -		feet	percent		--feet--	
lapponica								
N. Finland	229	65.2	25.5	30	65	--	--	--
N. Sweden	548	63.5	18.7	660	15	40	2.2	10.6
"	547	62.5	15.7	660	30	30	2.7	12.4
septentrionalis								
C. Sweden	523	61.3	16.0	700	40	20	3.4	16.2
"	524	61.3	17.9	100	5	5	3.7	16.1
"	522	60.9	16.5	700	15	10	3.7	16.5
"	544	60.4	14.9	800	15	10	4.3	18.3
"	222	60.2	15.0	800	25	10	4.6	19.6
"	521	60.0	18.0	100	10	0	4.0	17.0
"	543	59.9	12.9	700	20	5	3.6	15.5
S. Finland	233	61.5	26.0	500	25	30	3.8	17.1
"	228	60.4	25.4	200	30	35	3.8	17.5
S. Norway	201	60.5	3.2	100	0	5	3.8	16.5
"	273	59.7	9.5	600	5	10	5.0	16.1
"	275	59.8	11.5	700	20	5	3.4	15.0
"	276R	59.8	11.5	700	--	10	2.7	18.0
"	278	59.8	11.5	700	15	5	2.4	13.8
"	281	59.8	11.5	700	65	40	3.2	15.2
rigensis								
N. Latvia	224	57.5	25,8	300	10	15	4.4	18.9
"	223	57.7	26.3	230	45	0	5.0	20.8
S. Sweden	541	57.-	15.6	500	10	10	5.4	21.4
"	550	55.9	14.1	100	10	0	5.2	19.7
uralensis								
Ural	259	56.9	63.2	300	10	20	4.2	19.5
"	257	56.8	65.0	300	35	25	4.7	20.6
monogolica								
Siberia	234	56.0	95.0	--	25	5	5.0	19.7
altaica								
Siberia	227	54.0	94.0	500	15	20	4.3	17.5
"	255	52.4	117.5	2000	5	40	3.6	17.0
polinica								
N. Poland	211	53.8	20.3	400	5	0	5.9	23.1
"	317	53.7	20.5	600	15	5	5.5	22.8
borussica								
N. Germany	202	53.-	10.6	400	0	5	6.5	23.6

Table 1 continued--

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Origin of seedlots				Mortality		Height	
Variety, region	MSFG seed lot number	North latitude	East longitude	Elevation	in 4 yrs	after restoration	at 8 yrs	at 14 yrs
		- degrees -		feet	percent		--feet--	
E. Germany	365	53.5	12.2	100	25	5	5.5	22.0
(Gustrow)	366	53.5	12,2	100	20	0	6.4	28.8
"	370	53.5	12,2	100	20	20	6.4	23.9
"	372	53.5	12.2	100	60	50	5.5	23.3
"	373	53.5	12.2	100	35	15	5.4	22.5
"	380	53.5	12.2	100	30	10	5.5	22.4
"	321	53.2	13.1	260	5	0	7.4	24.7
(Neu-	323	53.2	13.1	260	40	25	6.5	24.0
streliz)	324	53.2	13.1	260	30	35	6.9	24.7
"	329	53.2	13.1	260	10	10	6.5	24.7
"	331	53.2	13.1	260	45	0	6.9	24.7
"	332	53.2	13.1	260	0	0	7.6	24.1
"	334	53.2	13.1	260	20	15	7.1	24.4
hercynica								
C. Germany	208	50.6	9.7	--	0	5	6.4	22.2
"	525	50.4	12.2	1500	35	0	5.2	21.7
"	209	50.3	12.2	1900	20	10	5.8	22.8
"	207	49.7	11.2	--	25	15	6.2	23.5
Czecho-	312	50.9	15.1	2000	0	5	7.0	23.4
slovalia	313	50.7	15.2	1600	10	0	6.5	23.4
"	311	50.5	14.7	1000	5	0	6.7	23.8
"	309	49.1	13.3	2200	5	0	6.1	23.2
"	305	49.-	14.7	1300	5	10	6.7	24.3
"	314	48.9	20.5	2700	60	10	5.3	22.5
S. Germany	248P	--	--	--	20	0	7.0	25.0
"	203	48.2	8.3	--	0	0	4.4	22.2
Austria	319D	--	--	--	5	0	7.0	24.1
"	205	47.2	11.3	3000	25	5	5.5	21.4
haguensis								
S. Germany	252	49.3	7.9	1300	0	0	7.2	24.4
N. France	235	48.2	9.2	2200	10	0	6.6	23.9
Belguim	318P	--	--	--	0	0	8.4	25.5
New York	225P	--	--	--	0	10	6.7	24.3
Belgium	286P	--	--	--	30	25	8.4	25.0
(Achel)	290P	--	--	--	10	0	7.3	25.9
"	292P	--	--	--	20	20	7.2	24.9
"	296P	--	--	--	25	15	5.8	23.2
Belgium	297P	--	--	--	25	0	6.6	25.7
(Hechtel)	299P	--	--	--	35	25	6.3	23.1
"	300P	--	--	--	45	15	6.7	24.3
"	301P	--	--	--	35	5	6.8	22.5

Table 1 continued--

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Origin of seedlots				Mortality		Height	
Variety, region	MSFG seed lot number	North latitude	East longitude	Elevation	in 4 yrs	after restoration	at 8 yrs	at 14 yrs
		- degrees -		feet	percent		--feet--	
'East Anglia'								
England	269P	--	--	--	5	0	5.7	23.4
scotia								
Scotland	268	57.2	3.8	--	0	10	5.0	19.5
aquitana								
? France	249D	--	--	--	10	20	4.8	17.6
France	320D	45.-	4.-	3000	60	55	3.9	17.8
"	239	45.3	3.7	3300	65	25	3.7	19.8
"	316D	45.1	3.5	3500	60	35	4.0	20.6
"	212	45.-	4.-	--	25	15	5.3	20.8
"	240	42.6	2.1	5000	70	--	--	--
iberica								
Spain	246	41.8	2.8	3900	15	0	5.0	21.5
"	247	42.3	0.5	3700	20	15	4.3	18.6
"	219	40.8	4.0	4900	25	5	4.7	21.5
"	218	40.3	5.2	3700	10	10	5.0	21.3
armena								
Turkey	221	40.5	32.7	4900	25	10	4.0	18.9
"	221R	40.5	32.7	4900	--	35	2.7	18.0
Approximate difference needed for significance								
L.S.D. at 5 percent level					35	28	1.3	4.3
L.S.D. at 1 percent level					54	37	1.7	3.3
Plantation average (per 20 trees per source)					12	12	5.3	21.0

(1) Designation of seed sources to varieties followed Wright et al., 1966. N = Northern; S = Southern; C = Central; E = Eastern

(2) "MSFG" indicate seedlot-number of Michigan State University. P = seedlots from plantations; D = seedlots from commercial dealers; R = trees planted two years later than others. Bars connect seedlots from different trees in the same stand.

(7) Mortality at age 14, after all dead trees were replaced at four years after planting.

Table 2.--Relationships among various characteristics of Scotch pine (*P. sylvestris*) and their relationships to the basic factors of the provenance. Two asterisks indicate correlation coefficients (r) that are significant at the 1 percent level, one asterisk - significant at the 5 percent level. Degrees of freedom varied from 40 to 79. Color of foliage was graded with respect to its intensity from yellow to blue.

Variables (Y_1):	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Provenance									
Variables (Y_2)	Latitude	Longitude	Elevation	Mortality C.Md., 7 yrs	Mortality C.Md., 14 yrs	Height C.Md., 8 yrs	Height C.Md., 14 yrs	Height Mich., 3 yrs	Height W.Md., 8 yrs	Color C.Md., 8 yrs
(6) Mortality, C.Md., 7 yrs	-.10	-.07	.18							
(7) " C.Md., 14 yrs	.06	.23	.10	.55**						
(8) Height, C.Md., 8 yrs	-.30*	-.18	-.17	-.23	-.43**					
(9) " C.Md., 14 yrs	-.48**	-.18	.00	-.09	-.43**	.81**				
(10) " Mich., 3 yrs	-.57**	-.21	.26	-.12	-.50**	.83**	.91**			
(11) " W.Md., 8 yrs	-.58**	-.21	.26	-.54**	-.47**	.91**	.92**	.92**		
(12) Color, C.Md., 8 yrs	-.93**	-.37**	.75**	.01	-.07	.37**	.45**	.48**	.53**	
(13) Leaf length, C.Md., 8 yrs	-.20	-.05	-.29*	-.01	-.05	.88**	.80**	.77**	.87**	.24*
Variables (Y_1):	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

populations for rapid growth at the age of eight years could have been based on the determination coefficient of 65.6 (r^1=.656). Some strains that were outstanding at the age of 14 years, were only average at the age of 8. This observation applies to the populations from Neustrelitz, East Germany, and to some others. Also, some height ranks changed; for instance, the Belgium population No. 318P, that was most outstanding at age 8, was surpassed by the Belgium population No. 290P,

The 14-year heights in Central Maryland continued to show a strong relationship to the leaf-lengths (r=,80). Also, the heights were positively correlated with the intensity of foliage-color toward bluish-green (r=.45).

When searching for individual strains for rapid growth, three groups deserve special consideration: (1) populations from Belgium plantations in Achel and Hechtel, (2) populations from a plantation in Neustrelitz, East Germany, and (3) some populations of variety <u>hercynica.</u> This last group includes the population No. 225P from the plantation in Boonsville, New York,

Efficiency of the Balanced Lattice Square Design.--Theoretically, experiments designed in balanced lattice squares permit a double control of "errors," because every pair of populations occurs together either in the same row or in the same column (Cochran and Cox, 1950). Also, population-means can be adjusted for differences among the rows and columns of each square. For experiments with forest trees this advanced design is seldom used, and it needs more detailed study. An opportunity to compare the efficiencies of two experimental designs - Randomized Blocks versus Balanced Lattice Squares - was undertaken on the basis of data available as part of this report.

First, the experiment was analyzed as five (5) Randomized Blocks, where Rows and Columns are amalgamated with "error," giving the following:

Source	d.f.	s.s.	m.s.	
Blocks	4	69.2	17.30	
Populations	80	4745.3	59.32	13.27**
Errors	320	1414.6	4 47	
TOTAL	404	6229.2		

* significant at 0.01 level

The regular analysis of variance for Balanced Lattice Squares provided components for the adjustment of the "population" means but gave no basis for an exact F-test, because the population error "m.s." was based on the non-adjusted "population" means.

The adjusted "m.s." for "population" was calculated from the sum of squares of deviations of the adjusted population totals (=23,624.25); this sum was divided by five (5) because of five replicates (=4,724.85); and further this value was divided by 80 degrees of freedom, giving the value of 59,06.

The adjusted "effective error m.s." was also calculated using Cochran and Cox formula; this value equalled 4.51. Finally, these adjusted values gave the F-ratio of 13.10. The complete data on this analysis of variance follow:

Source	d.f.	s.s.	m.s.	m.s. (adj.)	F
Replications	4	69.2	17.30		
Populations	80	4745.3	59.32	59.06	13.10**
Rows (adj.)	40	193.9	4.85		
Columns (adj.)	40	148.9	3.73		
Error	240	1071.9	4.47	4.51	
TOTAL	404	6229.2			

** significant at 0.01 level

Comparison of the error "m.s." from the randomized blocks (=4.47) versus the "effective" error "m.s." from the balanced lattice squares (=4.51) indicated that both experimental designs were about equally efficient, and no increased efficiency was achieved by arranging the sources in lattice squares.

Practical use of the results in Maryland.--These and other studies of Scotch pine in Maryland indicated that some populations from Belgium plantations and from West Germany had exceptionally good growth rates (Genys, 1970). To make a practical use of this information we contacted appropriate cooperators in Europe, and received ten (10) seedlots from individual trees in the plantation at Achel, Belgium (related to MSFG 286-292), one (1) seedlot (bulked) from the plantation in Hechtel, Belgium (related to MSFG 296-301, bulked) and one (1) seedlot from Forstamt Elmstein Sud in West Germany (related to MSFG 252, that grew most rapidly in western Maryland).

Field experiments with these selected populations were established in three locations. Two other seed-sources of Scotch pine, and representatives of three native pines were included for comparison. In due time, these plantations will be converted to orchards for production of our own seed of Pinus sylvestris var. haguensis.

The studies in Maryland indicated also that population MSFG No. 218 from Spain had exceptionally beautiful color and other desirable traits from Christmas trees. We selected one tree in each of the five 4-tree plots and used these five clones for grafting. Grafted seedlings were planted near Annapolis, Maryland, for future production of our own seeds of P. sylvestris var. iberica (MSFG No. 218).

Figure 1.--Two, 10-year old geographic strains of Scotch pine, Pinus sylvestris, studied in Maryland. The row of trees on the right, from the northern region of Scandinavia, were small and had a yellowish foliage in the fall; the row of trees on the left, grown from seeds collected in Achel, Belgium, were two or three times larger, and had dark green leaves.

Figure 2.--Trees from Spain (right front) grew slower than the central European strains (upper left), but their shape and foliage color qualified them as beautiful Christmas trees.

Figure 3.--Racial variation of Scotch pine studied 12 years in Maryland's Piedmont Plateau. Trees from northern Finland (on the left) grew about four feet and died; trees from central Europe (on the right) grew 20 to 30 feet high.

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