Table 1. — Location and climate at place of origin of Scotch pine provenances used in the study of differences in root types.

MSFG No., Country (a)	Lat. N	Long. E	Elev.	Temperature Annual	Temperature April-Sept.	Precipitation Annual	Precipitation April-Sept.	Index of Aridity (b) Annual	Index of Aridity (b) April-Sept.
	°	°	feet	°C	°C	millimeters		number	
var. mongolica									
254 SIB	60.8	131.6	2500	-11.6	8.1	188	145	188+	8.0
255 SIB	52.4	117.7	2000	3.3	11.3	377	342	28.4	16.1
var. lapponica									
549 SWE	64.5	18.7	800	0.6	8.0	493	310	46.7	17.2
548 SWE	63.5	18.7	700	2.0	8.5	568	299	47.3	16.2
547 SWE	62.5	15.7	700	2.9	9.1	525	332	40.7	17.4
546 SWE	60.9	13.4	1500	1.2	8.6	617	383	55.1	20.6
var. septentrionalis									
523 SWE	61.3	16.0	700	4.8	11.3	557	354	37.6	16.6
544 SWE	60.4	14.9	800	6.2	12.6	630	347	38.9	15.4
222 SWE	60.2	15.0	800	4.8	11.3	557	354	37.6	16.6
543 SWE	59.9	12.0	700	6.2	12.6	630	347	38.9	15.4
273 SWE	59.7	9.5	600	3.2	10.0	811	482	61.4	24.1
var. rigensis									
542 SWE	58.8	14.3	400	6.2	12.6	630	347	38.9	15.4
541 SWE	57.0	15.6	500	6.2	11.8	533	334	32.9	15.3
550 SWE	55.9	14.1	100	6.9	12.0	468	266	27.7	12.1
var. altaica									
256 SIB	56.7	96.3	1300	1.8	9.3	249	191	21.1	9.9
234 SIB	56.0	95.0	600	1.8	9.3	249	191	21.1	9.9
var. polonica									
317 POL	53.7	20.5	500	7.1	13.6	568	372	33.2	15.8
var. hercynica									
204 GER	50.8	9.7	1300	8.6	14.1	592	337	31.8	14.0
527 GER	50.8	13.7	1800	7.5	13.1	746	429	42.6	18.6
528 GER	50.6	12.0	1500	7.7	13.4	608	388	34.4	16.6
311 CZE	50.5	14.7	1000	9.0	15.6	490	335	25.8	13.1
526 GER	50.4	12.2	1700	6.2	11.9	762	444	47.0	20.3
307 CZE	49.9	17.9	800	8.8	15.5	630	407	33.5	16.0
306 CZE	49.2	14.0	1500	8.2	14.1	606	424	33.3	17.6
var. haguenensis									
318 BEL (c)	51.2	5.5	--	9.3	13.8	825	416	42.7	17.5
530 BEL (c)	50.0	5.0	--	7.4	11.9	1251	570	71.9	26.0
241 FRA	49.1	7.4	800	9.2	14.7	734	384	38.2	15.5
251 GER	49.1	8.1	500	9.9	15.5	536	305	26.9	12.0
253 GER	49.1	7.8	1300	9.5	15.0	612	338	31.4	13.5
237 FRA	48.8	7.8	500	9.8	15.7	777	441	39.2	17.2
var. illyrica									
242 YUG	43.9	19.4	1300	9.5	16.0	791	441	40.6	17.0
var. rhodopaea									
243 GRE	41.5	24.2	5600	7.4	12.7	2460	1190	141.4	52.4
551 GRE	41.3	23.4	5000	7.4	12.7	2460	1190	141.4	52.4
var. armena									
221 TUR	40.5	32.7	5000	11.6	17.7	345	147	16.0	5.3
263 GEO	41.8	43.4	3400	12.2	19.1	533	357	24.0	12.3
264 GEO	41.7	43.5	4900	12.2	19.1	533	357	24.0	12.3
261 GEO	41.6	42.6	3400	12.2	19.1	533	357	24.0	12.3
var. aquitana									
235 FRA	48.2	7.2	2200	8.9	14.5	1372	699	72.6	28.5
239 FRA	45.3	3.7	3100	9.0	13.9	780	503	41.1	21.0
316 FRA	45.1	3.5	3200	9.0	13.9	780	503	41.1	21.0
320 FRA	45.0	4.0	3000	9.0	13.9	780	503	41.1	21.0
238 FRA	44.7	3.8	2900	9.0	13.9	858	445	45.2	18.6
240 FRA	42.6	2.1	4700	5.9	9.9	799	412	50.3	20.7
var. iberica									
245 SPA	40.7	-4.2	4900	11.9	17.5	508	264	23.2	9.6
218 SPA	40.0	-5.3	3700	10.0	15.3	366	174	18.3	6.9

(a) The numbers are those used in the Michigan State Forest Genetic accession record. The countries are BELgium, CZEchoslovakia, FRAnce, GEOrgian SSR, GERmany, GREece, NORway, SIBeria, SPAin, SWEden, TURkey, YUGoslavia.

(b) Index of aridity = $\frac{\text{Precipitation in millimeters}}{\text{Temperature in } ^{o}\text{C.} + 10}$

(c) Seed obtained from plantation.

In autumn 1958 an intensive provenance study of Scotch pine was initiated at Michigan State University. Seeds were collected from many native stands throughout the range of the species. These were sown in the University's research nursery in 1959, and were later placed in permanent test plantations (WRIGHT *et al.*, 1966). When the seedlings were lifted for outplanting, there seemed to be distinct differences in root types, as well as in top characters. Most southern origins had longer tap-roots and lateral root systems which were more poorly developed than those origins from further north. Half or more of the taproot and most of the lateral roots were often lost when southern origins were lifted. On more northerly origins less of the root system was damaged or lost in lifting. In subsequent outplantings survival was generally best for southern provenances. It was next best for seedlings from southern Scandinavia, Poland and central Siberia. Survival was poorest for seedlings from northern Scandinavia and northern and eastern Siberia.

The study reported here was one of four designed to investigate variations in root types of different geographic origins of Scotch pine in order to help explain differences in top growth and survival after outplanting. The specific objectives of this study were to classify the root systems of Scotch pine seedlings from different parts of the species range and to relate differences in root types to the climate of the place of origin.

Procedure

Forty five of the seed sources of Scotch pine originally collected for the provenance study conducted by WRIGHT and BULL (1963) were used in this study. Each seedlot was gathered by cooperators in Europe and Asia from ten or more average trees in a stand of several acres (*Table 1, Figure 1*).

The climatic data were compiled by JOHN L. RUBY (1964) and are from weather stations located as closely as possible to the stands from which the seeds were collected. In most cases the data apply to the area of collection; in a few cases to stations some miles from location of collection. An "Index of Aridity" was calculated using DE MARTONNE's (1926) formula: $\text{Index} = \frac{\text{precipitation in mm.}}{\text{temp. in } ^0\text{C} + 10}$. The smaller the index value, the drier the climate.

Seedlings were grown in the greenhouse for eight months using a randomized complete block design with four replications and two trees (containers) per plot. Seed was sown in January 1965 in individual containers, with five seeds per container. The containers were 7.5 inches deep and 3.7 inches square. Germination began nine days after sowing and was completed eight days later. Two weeks after germination the seedlings were thinned to one per container. The potting mixture consisted of one-third (by volume) each of builders sand, peat moss, and a sandy loam nursery soil. A complete fertilizer had been added to this mixture to give the equivalent of approximately 50 ppm each of N, P_2O_5, and K_2O. This coarse, porous mixture permitted unrestricted rooting and recovery of root systems with a minimum of damage.

The seedlings were watered at intervals to keep the moisture level near field capacity. After eight months, containers were taken from the greenhouse, dumped and the root systems carefully washed. The trees were measured immediately.

All analyses of variance were conducted by using means of the 2-tree plots as items. Provenance means were used as items in the correlation calculations.

Results

The data were grouped by the geographic varieties proposed by RUBY (1964). The patterns of root development generally followed RUBY's varietal patterns based on seed and 2-year growth characteristics and 5- to 7-year growth in NC-51 plantations (WRIGHT *et al.*, 1966). Departure from RUBY's groupings are discussed whenever appropriate.

There were decided differences in root characteristics of seedlings from different origins. Many were adaptive characters which could be correlated with environmental conditions in the areas from which seed was collected. Some could not be correlated. Seedlings of all provenances were tap-rooted. The degree to which this characteristic was expressed, particularly in relation to the type and extent of lateral root development, varied greatly between individual sources and between different varieties.

The Northern Varieties

These varieties cover the more northerly and colder portions of the Scotch pine range and include the following: *mongolica* from northern Siberia; *lapponica* from north-central Scandinavia; *septentrionalis* from southern Norway, south-central Sweden, southern Finland and adjacent parts of the USSR; *rigensis* from southern Sweden, Latvia, and adjacent parts of the USSR; and altaica from the Altai Mountain region of central Siberia. All were characterized by distinct tap root development, with lateral root extension generally restricted to branching from the upper portions of the tap root. There was very limited lateral extension from the lower portions of the tap root (*Figures 2 a, b, c*).

In recognizing two varieties of Scotch pine in central and eastern Siberia — var. *mongolica* (254, 255) and var. *altaica* (234, 256) — RUBY used previous varietal descriptions published by the Russians, while recognizing the possibility that recognition of more taxonomic entities might be warranted. In the study reported here, the two seedlots of var. *mongolica* differed markedly, as they did in WRIGHT and BULL's (1963) earlier study. MSFG 254, from the far north, was distinct in a number of ways (*Figure 2 a*). It was the smallest of all seed sources in all aspects of top and root development. Depth of tap root was limited, more so than lateral root extension. The area from which seed of MSFG 254 was collected has a very severe climate (*Table 1*). The average annual temperature is extremely low (—11.6^0 C), the growing-season temperature is relatively warm (8.1^0 C), and rainfall is extremely low (145 millimeters). It appears that root system of this source are adapted to this combination of factors. Shallow depth of rooting is probably an adaptive character correlated with permafrost at a shallow depth in the soils of the region. The growing season aridity index for the area from which MSFG 254 was collected is low and the large lateral root extension in relation to tap root length may be a response to the dry growing season. Utkin (1958) found that roots of Scotch pine seldom penetrated into soil layers where maximum temperatures were below 3^0 to 4^0 C. He also concluded that surface rooting of Scotch pine made best utilization of available moisture in permafrost regions where precipitation is low.

MSFG 255 from southeastern Siberia, the other source of var. *mongolica*, had faster top growth and a more moderate

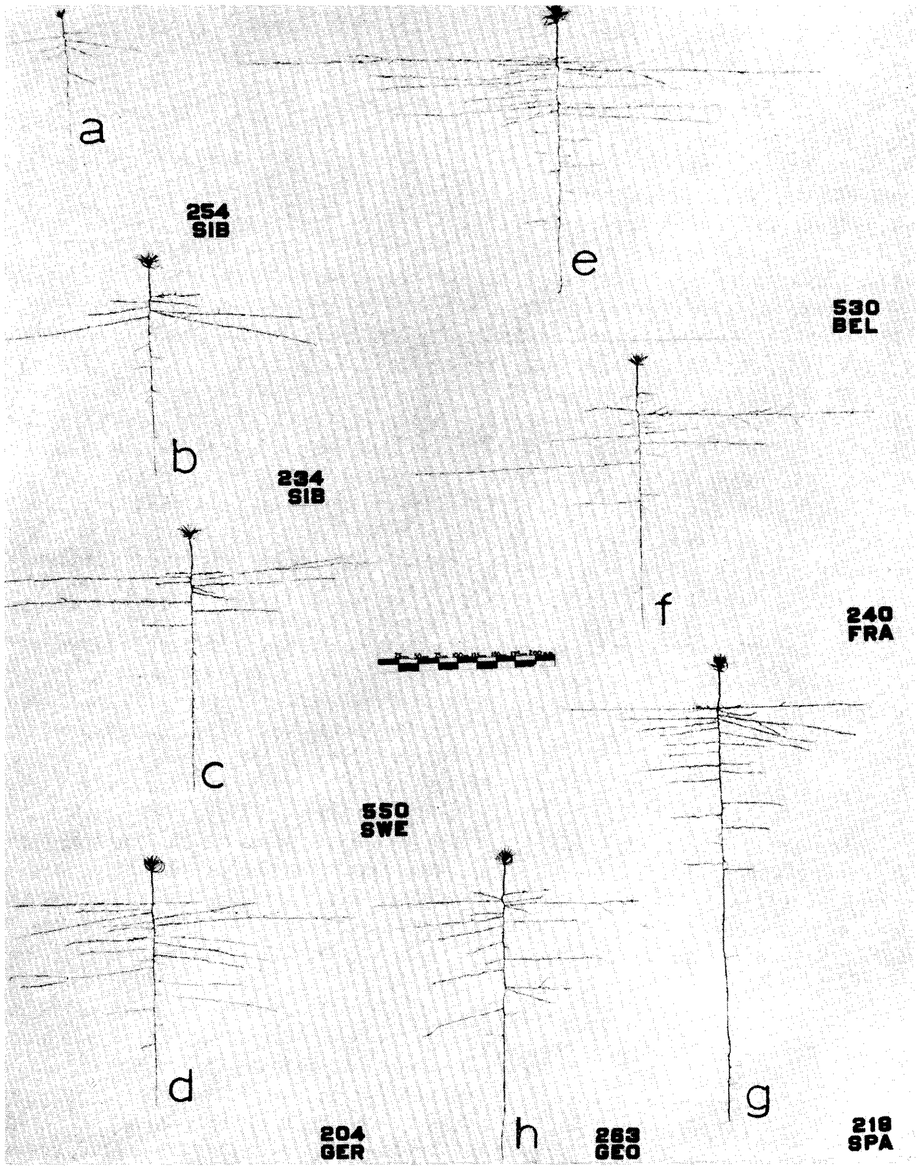

Figure 2. — Eight-month old seedlings of different Scotch pine provenances: a. MSFG 254 of var. *mongolica* from northeastern Siberia; b. MSFG 234 of var. *altaica* from central Siberia; c. MSFG 550 of var. *rigensis* from the southern tip of Sweden; d. MSFG 204 of var. *hercynica* from Germany; e. MSFG 530 of var. *haguenensis* from planted stands in Belgium; f. MSFG 240 of var. *aquitana* from southern France; g. MSFG 218 of var. *iberica* from Spain; and h. MSFG 263 of var. *armena* from the Georgian SSR.

ratio of lateral to tap root length than did MSFG 254. Root characteristics of MSFG 255 were very similar to those of the central Scandinavian var. *septentrionalis*. The two seedlots of var. *altaica (Figure 2 b)* were similar to each other and similar to seedlings of var. *rigensis* from southern Sweden *(Figure 2 c)*, despite the fact that the Siberian climate is much more rigorous than that of southern Sweden.

Root characteristics of the Scandinavian varieties generally varied on a north-south gradient. However, MSFG 546 and 273 had much less lateral root growth than did many sources from further north. As a result, root development (in terms of both depth of rooting and lateral extension) and top growth were better correlated with annual temperature than with latitude or origin. Correlation coefficients between average annual temperature and tap root length, lateral root length, and top length of Scandinavian sources were 0.87, 0.92, and 0.75 respectively (all significant at 1 percent level). First-year height growth data for seedlings of the same sources grown in the nursery (from WRIGHT and BULL's data) also showed correlation at the one percent level with average annual temperatures ($r = 0.86$).

Lateral root development of seedlings of north-Swedish MSFG 549 was similar to that of Siberian 254. However, tap roots were much longer in 549, possibly because of the higher average annual temperature. Permafrost, if present, probably does not come as close to the soil-surface in northern Sweden as in northeastern Siberia. This same characteristic of relatively greater tap root lengths in relation to lateral extension was common to other Scandinavian sources. Maximum root growth of the Swedish sources was shown by MSFG 550, the provenance from the most southerly and warmest part of the country *(Figure 2 c)*.

Attempts to correlate root development of Scandinavian sources with annual or growing season precipitation failed, possibly because moisture is not a critical factor (See *Table 1).*

The Central European Varieties

Origins from the following varieties from the central European area were used in the study: *polonica* from northeastern Poland; *hercynica* from Germany and Czechoslovakia; *haguenensis* from Belgium, northeastern France (Vosges Mountains), and western West Germany; and *illyrica* from Yugoslavia. Root characteristics of seedlings from central Europe were distinctly different from those of Scandinavian sources. Lateral roots were longer and branching of laterals occurred along the major portion of the tap root *(Figures 2 d, e).*

Varieties *haguenensis* and *polonica* were similar in root characteristics but were different from other central European types. Seedlings from these varieties had much longer and much more branched lateral roots than did provenances from almost any other portion of the species range *(Figure 2 e).* Origins of these varieties had the most favorable balance between top length and lateral root length. The fastest growing provenances of Scotch pine belong to var. *haguenensis.* It seems probable that its rapid growth is associated with favorable top length-root length ratios and with the long lateral and extensively branched root systems which can make maximum use of soil moisture and nutrients in the rooting zone.

The sources of var. *hercynica* had root systems which were generally shorter and less branched than those of vars. *polonica* and *haguenensis (Figure 2 d).* BIBLERIETHER (1964) found similar results in working with German origins of Scotch pine which had been field planted in 1936. Tap roots of sources from eastern Prussia (var. *hercynica)* were more distinct and laterals were less branched than those of provenances from western Germany (var. *haguenensis).*

MSFG 242 from Yugoslavia (var. *illyrica)* had root characteristics unlike those of other central European provenances to which it is similar in foliage and growth. This source, from an isolated portion of the range to the south of the continuous range common to the central European types, had roots similar to those of southern varieties.

Unlike the situation when dealing with Scandinavian sources, root characteristics of central European sources were not correlated closely with climate at place of origin. This is possibly the result of free interchange of genes in the more or less continuous population and climatic fluctuations in post-Pleistocene time. There is usually a lag between climatic change and evolutionary response to that change so that one need not expect perfect adaptation of modern genotypes to their particular microenvironments.

The Southern Varieties

These varieties cover the discontinuous southerly portions of the Scotch pine range and include the following varieties: var. *aquitana* from the Central Massif of France; var. *iberica* from Spain; var. *rhodopaea* from Greece; and var. *armena* from Turkey and the Georgian SSR. As a group, these varieties differed from those of northern and central Europe in a number of characters. In many characteristics the southern varieties also varied from each other.

Tap roots of most southern origins were generally longer and had higher weight per unit length than sources from other areas. They also had less branching of the lateral root systems. Tops of southern seedlings were heavier per unit length than those of northern and central European varieties *(Tables 2, 3).*

Seedlings from the Central Massif of France (var. *aquitana)* had root systems which were similar in general appearance to those of northern varieties. The majority of lateral roots grew from the upper portions of the tap root *(Figure 2 f).* Laterals for this variety were generally longer and less branched than those of the northern varieties, however. Root lengths were comparable to those of central European var. *hercynica,* but laterals of var. *aquitana* were less branched than in var. *hercynica.*

Root length was not correlated with climate at place of origin within var. *aquitana.* Neither could the similarities in root types between these sources and northern ones be explained on the basis of climate. Temperatures in the Central Massif are generally much higher than in northern Sweden and Siberia. It is possible that this root type may reflect an evolutionary response to weather conditions during Pleistocene glaciation. At that time, prevailing temperatures in the Central Massif would have been much colder than at present. This might have favored the development of types having lateral rooting near the surface areas, just as in present northern varieties.

The two sources from Spain (var. *iberica)* had the most distinctive root systems of all sources investigated *(Figure 2 g).* They had significantly longer tap roots than any other origin. Weight per unit length of the tap root was also very high. Lateral roots were generally short but numerous and were distributed along most of the tap root. As a result the root systems had a narrow, columnar appearance, with the highest percentage of total root weight in the taproot. Lateral roots of var. *iberica* had the fewest branches per unit of length of any source. The tops of Spanish seedlings were also significantly heavier in relation to their length than in other origins. This was not due to greater number or weight of needles, but to diameter (and possibly density) of the stem.

The strong tap roots of Spanish origins appear to be adaptive to Spanish climatic conditions *(Table 1).* Temperatures there are relatively high and precipitation is low. Effective precipitation is very low, as indicated by the small aridity index values. There are periods during midsummer when precipitation is only 10 to 20 millimeters per month. Under these conditions seedlings having a deep tap root with laterals concentrated along its length have a decided advantage in withstanding soil moisture depletion and drought conditions in the surface layers.

The seedlings of var. *armena* and var. *rhodopaea* came from three isolated areas in southern portions of the Scotch pine range — from Greece, Turkey and the Georgian SSR *(Figure 1).* All these sources exhibited less branching than sources from further north but none had the narrow, columnar root type of var. *iberica* nor lateral rooting confined to the upper portion of the tap root as in French var. *aquitana.*

Greek origins were characterized by less pronounced tap root development than those from Georgia and Turkey. The Greek provenances exhibited lower weights per unit length and more branching of lateral roots than did seedlings of var. *armena.* The Turkish and Georgian sources were nearly alike except that the Turkish origin had deeper tap roots *(Figure 2 h).*

Differences between var. *armena* and var. *rhodopaea* are probably associated with climatic differences. The Greek provenances were collected from areas with very high rain-

Table 2. — Shoot and root growth of Scotch pine provenances grown eight months in the greenhouse.

MSFG No., Country of Origin	Length of: Shoot	Length of: Tap Root	Length of: Lat. Root	Weight of: Shoot	Weight of: Tap Root	Weight of: Lat. Root	Root Wt./Unit Length	Top-Root Ratios: Top Length / Tot. Rt. Length	Top-Root Ratios: Top Weight / Tot. Rt. Weight	Root Ratios: Length: Total Lateral / Taproot	Root Ratios: Length: Longest Lateral / Taproot	Root Ratios: Weight: Lateral Root / Taproot
	mm.	cm.	cm.	---milligrams----			mg./cm.	-----number------		----------number---------		
var. mongolica												
254 SIB	32	15	90	25	8	22	.50	.020	.86	5.8	1.16	2.9
255 SIB	40	24	119	41	11	29	.45	.028	1.02	4.9	.86	2.7
var. lapponica												
549 SWE	32	20	105	18	9	22	.48	.026	.58	5.4	.75	2.3
548 SWE	40	21	134	26	8	31	.39	.026	.66	6.4	1.02	3.9
547 SWE	42	21	172	26	10	40	.46	.022	.53	8.3	1.05	4.2
546 SWE	40	20	118	33	7	28	.36	.029	.96	6.0	1.03	3.9
var. septentrionalis												
523 SWE	41	25	158	34	10	35	.41	.023	.75	6.4	.90	3.7
544 SWE	45	25	180	38	13	41	.55	.023	.72	7.2	1.03	3.1
222 SWE	43	22	171	35	10	42	.46	.023	.68	7.8	1.01	4.1
543 SWE	43	26	187	34	14	35	.54	.021	.68	7.2	1.05	2.6
273 NOR	38	25	156	30	13	31	.51	.021	.70	6.3	.97	2.4
var. rigensis												
542 SWE	39	27	175	34	14	46	.48	.020	.58	6.8	.92	3.7
541 SWE	42	24	175	33	11	36	.46	.022	.70	7.2	.88	3.3
550 SWE	47	28	195	41	12	49	.45	.021	.68	7.2	.99	4.1
var. altaica												
256 SIB	44	25	206	43	12	49	.47	.019	.72	8.1	1.07	4.2
234 SIB	43	26	191	41	9	43	.34	.031	.81	7.4	.87	4.9
var. polonica												
317 POL	50	27	268	58	14	61	.53	.018	.78	9.8	1.08	4.2
var. hercynica												
204 GER	49	28	202	52	14	44	.59	.022	.87	7.3	1.04	2.7
527 GER	49	28	247	47	15	56	.53	.018	.66	8.8	1.08	3.7
528 GER	52	28	265	47	13	59	.45	.018	.66	9.3	.95	4.6
311 CZE	49	28	234	46	12	62	.43	.019	.62	8.4	1.01	5.1
526 GER	48	26	242	53	15	52	.56	.018	.81	9.3	1.16	3.7
307 CZE	50	26	195	45	13	36	.49	.023	.95	7.4	.83	2.8
306 CZE	48	27	198	43	11	38	.44	.021	.89	7.3	.81	3.2
var. haguenensis												
318 BEL	54	27	308	57	15	60	.56	.016	.75	11.6	1.10	4.0
530 BEL	58	31	364	82	18	81	.60	.015	.82	11.6	1.09	4.4
241 FRA	53	32	312	47	14	67	.45	.015	.60	9.8	.88	4.5
251 GER	54	29	296	64	14	68	.50	.017	.78	10.2	1.16	4.7
253 GER	53	26	328	60	16	70	.60	.015	.70	12.6	1.26	4.5
237 FRA	57	26	276	47	15	47	.57	.020	.78	10.3	1.04	3.1
var. illyrica												
242 YUG	53	29	248	69	18	61	.66	.019	.87	8.8	.93	3.3
var. rhodopaea												
243 GRE	50	32	270	69	18	50	.57	.017	1.01	8.5	.86	2.7
551 GRE	51	30	259	62	20	52	.67	.018	.88	8.5	.90	2.6
var. armena												
221 TUR	54	36	306	74	32	85	.92	.016	.62	8.5	1.14	2.6
263 GEO	54	34	278	68	27	72	.77	.017	.69	8.1	.89	2.7
264 GEO	53	30	284	84	25	79	.81	.018	.81	9.5	1.05	3.3
261 GEO	52	30	255	70	29	63	.95	.017	.77	8.5	1.28	2.2
var. aquitana												
235 FRA	46	28	202	38	14	45	.50	.020	.65	7.2	1.20	3.5
239 FRA	46	28	249	59	18	60	.63	.017	.77	8.8	1.28	3.4
316 FRA	46	31	269	51	19	70	.63	.016	.58	8.7	1.19	3.6
320 FRA	48	27	228	49	19	44	.69	.019	.78	8.4	.91	2.4
238 FRA	44	28	238	56	18	50	.68	.017	.77	8.9	1.01	2.7
240 FRA	46	34	262	49	24	66	.71	.016	.56	7.8	.93	2.7
var. iberica												
245 SPA	54	46	312	81	51	76	1.13	.015	.64	6.9	.61	1.5
218 SPA	58	46	245	92	49	68	1.05	.020	.79	5.2	.51	1.4
$LSD_{.10}$	2.8	3.0	41	8	2.7	10	.08	.002	.04	1.6	.17	.7
$LSD_{.05}$	3.3	3.6	48	10	3.3	12	.09	.003	.04	2.0	.21	.8
$LSD_{.01}$	4.3	4.8	64	13	4.3	16	.11	.004	.06	2.6	.28	1.1

Table 3. — Growth data for Scotch pine progenies, summarized by variety.

Variety	Length of			Weight of			Root wt./ Unit Length	Top-Root Ratios		Root Ratios		
								Top Length / Tot. Rt. Length	Top Weight / Tot. Rt. Weight	Length		Weight
	Shoot	Tap Root	Lat. Root	Shoot	Tap Root	Lat. Root				Total Lateral / Taproot	Longest Lateral / Taproot	Lateral Root / Taproot
	mm.	cm.	cm.	milligrams			mg./cm.	number		number		
mongolica	36	15	105	33	10	25	.47	.024	.94	5.4	1.01	2.8
lapponica	39	20	132	26	9	30	.42	.026	.68	6.5	1.01	3.6
septentrionalis	42	24	170	34	12	37	.49	.023	.71	7.0	.99	3.2
rigensis	43	26	181	36	12	44	.46	.021	.65	7.1	.93	3.7
altaica	43	26	198	42	11	46	.41	.020	.76	7.7	.97	4.5
polonica	50	27	268	58	14	61	.53	.018	.78	9.8	1.08	4.2
hercynica	49	27	226	48	14	50	.50	.020	.78	8.4	.98	3.7
haguenensis	55	29	331	60	15	65	.53	.016	.74	11.0	1.09	4.4
illyrica	53	29	248	69	18	61	.66	.019	.87	8.8	.93	3.3
rhodopaea	51	31	265	65	19	51	.62	.017	.95	8.5	.88	2.7
armena	53	33	281	74	28	75	.86	.017	.72	8.7	1.09	2.7
aquitana	46	29	241	50	19	56	.64	.017	.69	8.2	1.09	3.0
iberica	56	46	278	86	50	72	.09	.017	.72	6.0	.56	1.4

fall and comparatively low temperatures, resulting in very high aridity index values. The Turkish and Georgian seeds, on the other hand, were collected in areas of limited precipitation and comparatively high temperatures. The lower weights per unit length of tops and root systems of the Greek sources were apparently a reflection of the more moist conditions under which they grow naturally. The Greek and south French sources are similar in this respect.

The distinct differences between the Georgian-Turkish and Greek populations may be explained by the migration barrier between the two, and the relatively slight differences between Turkish and Georgian sources to the absence of a distinct migration barrier.

Abstract

Root systems of seedlings of Scotch pine were studied after they had been grown from seed in the greenhouse for eight months. Forty five provenances were used, representing 13 different varieties from throughout the range of the species. All sources were tap-rooted. The degree to which this characteristic was expressed, particularly in relation to type and extent of lateral root development, varied greatly between individual sources and between varieties.

Seedlings of northern origins (vars. *mongolica, lapponica, septentrionalis, rigensis, altaica)* had root systems with lateral rooting confined to branching from upper portions of the tap root. Root length was well correlated with average annual temperature of the area of seed collection. Lateral roots of central European provenances (vars. *polonica, hercynica, haguenensis)* were longer and more branched, and they occurred along most of the tap root. Differences in root characteristics of central European origins could not be correlated with climate of the area of seed collection.

Tap roots of sources from isolated, southern portions of the range were generally long and had high weight per unit length. Branching of laterals was low. There was considerable variation in other characters and individual root types apparently developed in response to differences in precipitation and past evolutionary history. Provenances from southern France (var. *aquitana)* had root types which were similar in appearance to those of northern origins. Lateral rooting was confined to branching from upper portions of the tap root. This character may have developed in response to weather conditions prevailing during Pleistocene glaciation. Root systems of Spanish origins (var. *iberica)* had a narrow, columnar appearance. Tap roots were long and laterals short and extended from along most of the tap root. Root characteristics of this variety have apparently developed in response to warm, dry climatic conditions which prevail in the areas of seed collection. Greek origins (var. *rhodopaea)* from cool, moist climates had root types intermediate between those of other southern origins and those of central European sources. Provenances from Turkey and the Georgian SSR (var. *armena)* came from areas with relatively warm, dry climates. Tap roots were long but individual lateral roots were longer than those of Spanish origins.

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