Performance of Scotch Pine Varieties in the North Central Region[1]

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Scotch or Scots pine (*Pinus sylvestris* L.) is the most widespread forest tree of northern Eurasia. The species occurs naturally in most parts of Siberia as well as in all European countries except Eire, England, Denmark, and Portugal. Scotch pine is of primary commercial importance in northern Europe, where its range is continuous over large areas of low and medium elevation. There it is used for lumber and pulp. The species is of less importance in southern Europe, where the native stands are scattered in mountainous areas.

Scotch pine is an important exotic in the United States. The tree has been grown for three centuries, and thriving single specimens can be found in every section except the deep South. At first, Scotch pine was used as an ornamental. Around the turn of the century it was planted to a limited extent as a timber tree. During the past two decades it has become America's most important Christmas tree, and millions of seedlings are planted annually. Many of these Christmas trees will undoubtedly grow to sawlog and pulpwoad size.

Scotch pine was the subject of the original provenance research in forest trees. In the 1700's the Finns experimented with seedlings of different origins. In 1820 VILMORIN established an experiment in which he grew trees from many parts of Europe on his estate in France. In 1907 and again in 1938 the International Union of Forest Research Organizations (IUFRO) started large cooperative tests involving many different seedlots and several different planting sites. Two of the later IUFRO plantations werr located in northeastern United States, and provided data applicable to American practice (BALDWIN, 1955, 1956; WRIGHT and BALDWIN, 1957; ECHOLS, 1958; GERHOLD, 1959; and SCHREINER *et al.*, 1962). LANGLET (1936) conducted an intensive 2-year study of percent dry matter content in Swedish Scotch pine needles and more recently has made comparative trials of Swedish and continental origins.

The IUFRO work showed that the species is variable – in growth rate, bole form, foliage color, mineral content of foliage, and wood specific gravity. Belgian origins consistently grew most rapidly but were sometimes inferior in stem form. Latvian origins, which grew more slowly, always had good stem form. Trees from the far north grew very slowly, had needles with a high percent dry-matter content, and undesirable yellow foliage in the winter.

Earlier provenance studies did not sample populations in the southern and eastern parts of the species' range, and the plantations were limited to Europe and northeastern United States. Reliable data were not available on the performance of seed sources for use in central United States where the species is being grown on a large scale. The present study was untertaken for these reasons and also to provide material for studies on the mechanisms of growth.

Materials and Methods

Seed procurement. – In autumn 1958 letters were sent to European researchers, asking for seed from native Scotch pine in their loealities. Each collection was to be made from 10 average trees in one stand. The response was excellent. Seeds, accompanied by detailed origin data, were received from 108 native and 13 planted stands (*Figures* 1 *and* 2). The complete origin data are available on request.

The collectors took special care to authenticate "native-stand" samples and recorded possible doubts. Their opinions were later checked against the performance of seedlings in the nursery and plantations. They were confirmed in nearly all cases.

Nursery handling. – Details of nursery practice were reported by WRIGHT and BULL (1963). Trees destined for outplanting were sown in the fifth, unmeasured replicate of a nursery test at East Lansing, Michigan. Each seedlot was sown in a rectangular plot with a density after thinning of 50 seedlings per square foot. The seeds were sown in early May 1959 and germinated uniformly 3 weeks later. They were watered frequently, mulched overwinter, and maintainod weed-free at a high fertility level.

Trees for 1961 plantations were lifted after 2 years in the seedbeds. They were 50 to 100 percent larger than usual in

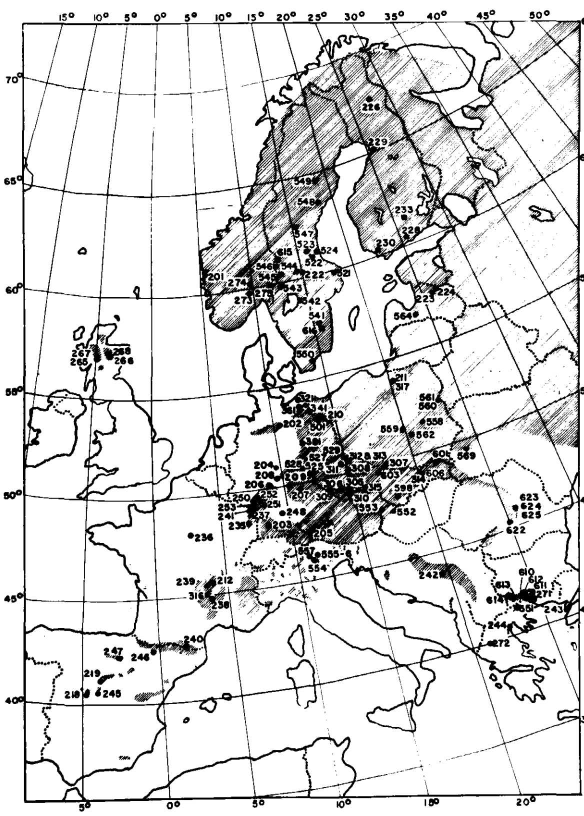

Figure 1. – Natural distribution (shaded) and location of parental Scotch pine stands (numbers) used in this study. Europe.

[1]) The paper is dedicated to W. LANGNER, Schmalenbeck on the occasion of his 60th birthday.

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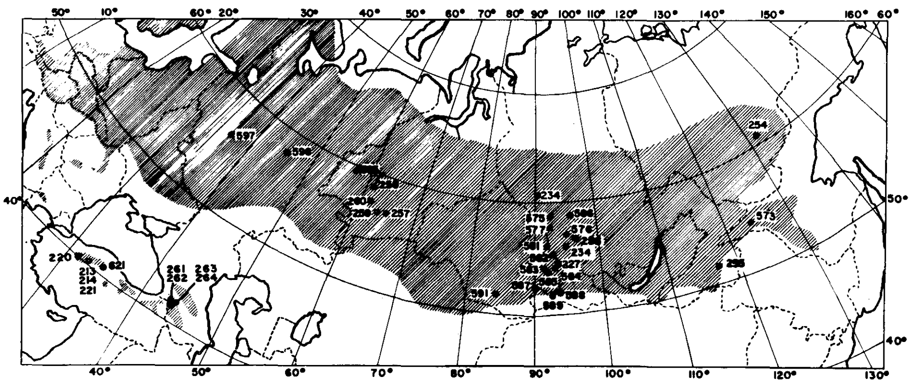

Figure 2. — Natural distribution (shaded) and location of parental Scotch pine stands (numbers) used in this study. Asia.

commercial nurseries. The smallest 10 percent of each seedlot were discarded. The fastest growing Belgian and German varieties had too small a root-top ratio. Otherwise most seedlings were ideal for outplanting. Stock for the six 1962 plantations was lined out for an additional year.

Lifting and shipping. — The trees were machine lifted between March 25 and April 15, 1961. Lifting and packing for one plantation required ½ to 1 day. The packing operation also included labelling every fourth tree with masking tape, tying the trees in 4-tree bundles, and placing one such 4-tree bundle in each replicate bundle. The trees were packed with their roots in moist sphagnum and wrapped in heavy waterproof paper.

Trees for southern Michigan plantations were trucked to the planting site and planted within 2 days. Trees for other states were shipped via surface carrier. Transit times varied from 2 days to 2 weeks.

Experimental design and statistical analysis. — Location of experimental plantations is shown in *Figure 3*. The cooperators used a randomized complete block design, with 2 (Illinois) or 4 (others) trees per plot and 4 to 10 replications per plantation. Row-plots were used and most cooperators made the tree-rows straight in both directions. One or two border rows were planted around each plantation. Spacing was 7 × 7 or 8 × 8 feet (7 × 14 in Nebraska).

Most plantations contained from 60 to 108 different origins, chosen to represent the widest possible geographic range.

The most valuable growth data came from plantations with less than 20 percent mortality, with less than 3 percent missing plots. Seedlot means were substituted for missing-plot values. For comparison purposes, missing-plot values were calculated in the orthodox manner for some sets of data. The size of the error variance was not affected appreciably by the use of the shortcut method.

Each cooperator performed analyses of variance on his own data, and transmitted the data and analyses to Michigan State University. There the all-plantation seedlot and variety means and pooled error variances were calculated.

The Varieties of Scotch Pine

Scotch pine has a continuous range in northeastern Europe and much of Siberia, where it is difficult to draw exact lines separating one population from another. In southern and western Europe the range is discontinuous, and neighboring populations may be genetically distinct.

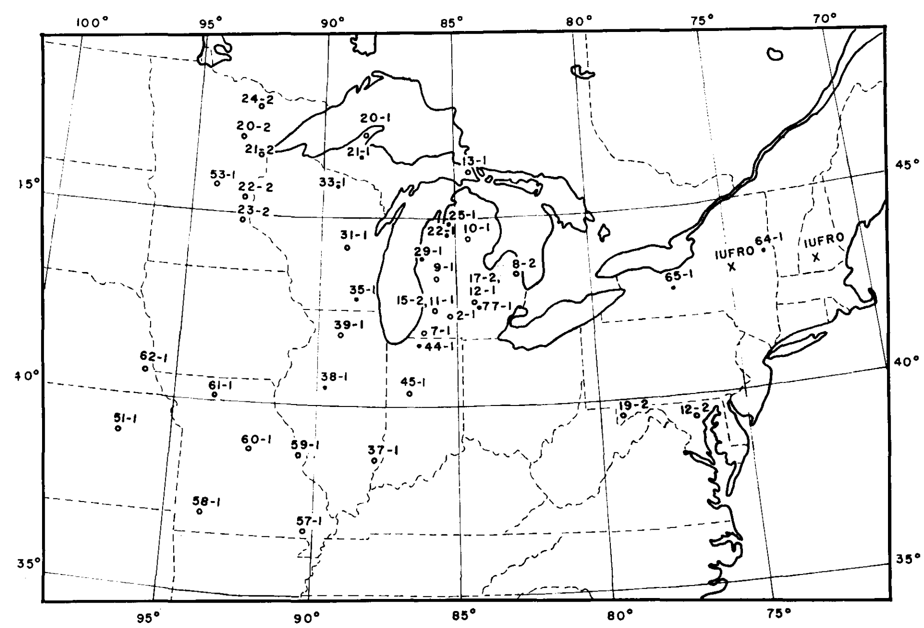

Figure 3. — Location of NC-51 and IUFRO test plantations of Scotch pine. The second number signifies date (1 = 1961, 2 = 1962).

Two steps were involved in assigning correct varietal names. The first was to delimit populations distinct enough to merit separate recognition. This was done by means of multivariate analyses of several traits measured in 2-year-old seedlings (WRIGHT and BULL, 1963) and of cone and needle characteristics of wild trees (RUBY, 1964). RUBY also correlated genetic and phenotypic variation patterns to ascertain which populations could be recognized in nature as well as in uniform-environment experiments.

The second step was choice of the proper names. RUBY did this by consulting original descriptions for the 52 geographic varieties described by taxonomists during the past century and establishing priority under the International Code of Botanical Nomenclature. He recognized 21 geographic varieties as valid and showed which names should be used; his paper is the basis for the nomenclature used in this report. One point of uncertainty in the nomenclature should be mentioned: the identity of the type variety, *Pinus sylvestris* var. *sylvestris*, is still in doubt because we do not know whether LINNAEUS' type specimen was collected in Germany or southern Sweden.

The south European varieties are distinct enough as to be identified with certainty when grown under uniform conditions with other varieties. This is not true of several north European varieties, which overlap to a considerable degree. In such cases it is not possible to recognize a single herbarium specimen with more than 30 or 35 percent certainty. However, the certainty approaches 100 percent when one examines a series of specimens from several different stands.

In any specific trait the variation within variety is from 10 to 20 percent as great as that found within the species as a whole. LANGLET (1936) found a pattern in the within-variety variation in percent dry weight of needles in Sweden. In other varieties the within-variety variation is best considered as random.

The seedlot numbers included in each variety are as follows:

lapponica (northern Scandinavia) — 226, 229, 546, 547, 548, 549.
mongolica (eastern Siberia) — 234, 254.
altaica (southern Siberia) — 227, 255, 256.
sepentrionalis (south-central Sweden and Norway, southern Finland) — 201, 222, 228, 230, 232, 233, 273, 274, 275, 521, 522, 523, 524, 543, 544, 545.
rigensis (Latvian SSR, S. Sweden) — 223, 224, 541, 542, 550.
uralensis (Ural Mountains) — 257, 258, 259, 260.
polonica (Poland) — 211, 317.
borussica (lowlands of northeastern Germany) — 202, 210.
hercynica (Germany, Czechoslovakia) — 203, 204, 207, 208, 209, 248, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 319, 525, 526, 527, 528, 529.
haguenensis (Belgium, Vosges Mountains of France, adjacent Germany) — 206, 250, 251, 252, 253, 236, 237, 241, 318, 530.
'East Anglia' (England) — 269, 270.
pannonica (Hungary) — 552, 553.
'N. Italy' — 554, 555, 556, 557.
illyrica (Yugoslavia) — 242.

Table 1. — Mortality after 1 year as related to location and date of planting, delay, and care. Mortality increased about 10 percent from the first to the seventh year.

Number, year	location of plantation	Planting date	Lifting-planting interval	Weed competition	Weed control method	Mortality Before Replacement	Mortality After Replacement
			days			percent	
77—61	Mich.	April 8	0	Heavy	CHEM[1]	1	—[2]
20—62	Minn.	May 10	1	Light	0	4	3
9—61	Mich.	April 4	1	Heavy	FURR	4	9
10—61	Mich.	April 15	1	Heavy	FURR	5	3
21—62	Minn.	May 2—8	1—7	Medium	0	6	3
64—61	N. Y.	May 12	15	Light	0	7	3
22—62	Minn.	April 29	1	Medium	0	7	3
13—61	Mich.	May 4	10	Medium	0	7	—
19—62	Md.	April 28	13	Medium	0	7	—
2—61	Mich.	April 3	1	Medium	FURR-CHEM	8	9
11—61	Mich.	April 19	1	Light	0	9	11
21—62	Minn.	May 14	1	Medium	0	10	—
57—61	Mo.	April 13—17	10—14	Medium	CULT	13	12
59—61	Mo.	April 17—19	14—16	Medium	0	15	—
12—61	Mich.	April 25	1	Light	0	17	8
20—61	Mich.	May 11	14	Heavy	FURR	17	—
7—61	Mich.	April 11	1	Heavy	CHEM	18	16
37—61	Ill.	April 13—15	8—13	Medium	0	18	19
60—61	Mo.	May 4—13	31—40	Medium	DISK	19	7
12—62	Md.	April 25	10	Heavy	DISK	19	—
39—61	Ill.	April 17	6	Light	FURR	22	16
58—61	Mo.	April 13—15	10—12	Medium	0	26	—
61—61	Mo.	May 11	38	Medium	CULT	26	—
62—62	Neb.	April 10	6	Heavy	CHEM-CULT	27	6
45—61	Ind.	May 15	46	Heavy	0	28	—
53—61	Minn.	April 29	12	Medium	0	33	—
38—61	Ill.	April 24	13	Heavy	0	33	30
22—61	Mich.	May 9	12	None	0	35	24
33—61	Wis.	May 23	35	Heavy	0	36	42
23—62	Minn.	April 28	1	Heavy	0	39	—
30—61	Wis.	May 10	23	Heavy	0	41	—
35—61	Wis.	May 24	36	Light	0	72	—
51—61	Kan.	April 11	7	Heavy	CULT	76	—

[1]) 0 = none or a slight scalp, FURR = double furrow before planting, CHEM = dalapon or amino-triazole to strips before planting, followed by simazine sprayed over trees, DISK = area disked before planting. CULT = mechanically cultivated.

[2]) No replacement practiced if there is a dash in this column.

scotia (Scotland) — 265, 266, 267, 268.
iberica (Spain) — 218, 219, 245, 246, 247.
aquitana (Central Massif of France) — 212, 238, 239, 240, 249, 316, 320.
rhodopaea (Greece) — 243, 244, 271, 272, 551.
armena (Turkey, Caucasus Mtns. of Georgian SSR) — 213, 214, 220, 221, 261, 262, 263, 264.

First-Year Mortality

First-year mortality, by plantation, is shown in *table 1.* It continued to increase from 1961 to 1965 in plantation 51—61 (Kansas), but not at other places. Most mortality became evident in late summer.

Replacement efforts were more successful with 2—1 than with 3—0 stock. The best results were obtained in Nebraska and Missouri, where numbers of missing trees were reduced from 27 to 6 percent and from 19 to 7 percent respectively. Half the replacements have caught up with the original trees and were measured.

The missing-plot problem was serious in plantations having more than 20 percent mortality. Also, data from such plantations are of doubtful value because of high error variances. Hence, few measurements have been made on such plantations.

Effects of quality of planting stock and care. — Ten percent of the trees were culled before packing. Examination of dead trees pulled from well-maintained plantations indicated that an additional 5 percent should have been culled, as unlikely to succeed under any conditions.

Ages of planting stock could be compared in Minnesota. A plantation established in 1961 with 2—0 seedlings suffered 33 percent loss; four plantations established a year later with 2—1 transplants suffered 4, 6, 10, and 39 percent loss.

Amount of care was most responsible for the variation shown in *table 1.* Trouble started in the packing shed. Packing was sufficient for a few days but not for stock delayed 2 weeks in transit. Further delays between receipt and planting occurred in some cases. The 1961 experience caused a change to air shipment in subsequent NC-51 work.

Slit planting or planting in a small scalp was satisfactory in a light weed cover, but not where competition was heavy.

Table 2. — First-year mortality by variety and region of origin in 19 plantations established with 2—0 stock in 1961.[1])

Variety and region of origin	Mortality in plantations with average mortality of 4-9 %	13-21 %	26-27 %	35-42 %
	percent			
lapponica, mongolica FIN SIB SWE[2])	17	43	30	70
altaica, uralensis, septentrionalis, polonica FIN NOR POL SIB SWE	4	17	34	38
rigensis LAT SWE	6	10	24	28
borussica, carpatica, haguenensis, hercynica, pannonica BEL CZE N. FRA GER HUN ITA	8	21	28	41
armena, illyrica, rhodopaea GEO GRE TUR YUG	7	16	26	34
aquitana, iberica, scotica, scotica X? ENG S. FRA SCO SPA	3	11	23	23

[1]) Significance was determined by Chi-square tests. Varieties grouped together did not differ from each other at the 5 percent level. Groups of varieties differed significantly from each other in at least one group of plantations.

[2]) BELgium, CZEchoslovakia, ENGland, FINland, FRAnce, GEOrgian SSR, GERmany, GREece, HUNgary, ITAly, LATvian SSR, NORway, POLand, SCOtland, SIBeria, SWEden, TURkey, YUGoslavia.

Mortality was usually light if the trees were planted in the bottom of double furrows, on chemically treated strips (dalapon or amino-triazole prior to planting, simazine after planting), or on mechanically bared strips to which simazine was applied after planting. Disking prior to planting, mowing, and the application of simazine to weedy ground were relatively inneffective.

Effect of site. — Site conditions *per se* were known to be the cause of heavy mortality in only one case. Plantation 51—61 (Kansas) was carefully planted, cultivated, and even watered. Evidently the hot dry Kansas summers were too much for Scotch pine.

Genetic differences. — There were several statistically significant differences among seedlots within variety and seedlot × plantation interactions. For example, MSFG 550 (southern Sweden) suffered 2 and 48 percent mortality, respectively, in plantations 7—61 (average mortality 17 percent) and 13—61 (average mortality 7 percent). However, these differences involving single seedlots may have little genetic significance because of the method of plantation establishment. All trees of one seedlot were lifted from the same part of the nursery, and thus shared common environmental conditions while still in the nursery.

There were pronounced differences in mortality of the 2—0 stock planted in 1961 *(Table 2).* Varieties from Spain, southern France, and Scotland suffered least, regardless of whether average mortality for the plantation was 4 or 40 percent. This was unexpected because Spanish trees had long taproots and poorly developed laterals. Evidently, the ability to grow a long taproot reflected ability to regenerate damaged roots quickly after transplanting.

Next best survival was observed among seedlings from southern Scandinavia, Poland, and Siberia. These had a fibrous root system which was lifted almost intact, medium-sized tops, and an excellent root-shoot ratio. The fast growing central European seedlings were somewhat less successful. They had fibrous root systems but unfavorable root-shoot ratios.

Seedlings from northern Scandinavia and Siberia suffered most. They had excellent fibrous root systems which were scarcely touched by the lifter blade set for a 6-inch depth. Perhaps they would have thrived if the upper 6 inches of soil had been kept moist constantly. However, it was not, and their small size was disadvantageous.

The mortality story was different for plantations established in 1962 with 2—1 transplants *(Table 3).* In Minnesota, Spanish trees suffered the heaviest mortality, primarily because of winter killing. In Nebraska and Maryland, trees from the Ural Mountains and southern France suffered most.

The better survival of 2—1 (than of 2—0) Scandinavian trees is probably due to their greater overall size. The good

Table 3. — Regional differences in first-year mortality in 1962 plantations established with 2—1 stock.

Region of origin	Mortality in Minn.	Neb.	Md.
	percent		
Scandinavia	3	21	16
Siberia and Ural Mtns.	6	68*	27*
Great Britain, Cent. and SE Europe	3	24	13
Sou. France	7	43	35*
Spain	38*	30	17
Average	5	27	18

* Differs from plantation average at 5 percent level.

Table 4. — Relative height of Scotch pine varieties at test sites in five North Central states.

Variety	Country of	Ave. all sites	Relative height at test plantation in: S. Mich.							N. Mich.			Minnesota			Neb.	Mo.		Iowa
			2-61	7-61	9-61	10-61	11-61	12-61	77-61	13-61	20-61	53-61	20-62	21-62	22-62	62-62	57-61	60-61	
			percent of plantation mean																
Scandinavian and Siberian Varieties																			
lapponica	FIN[1]) SWEden	44	50	37*	45	50	41*	41	—	51*	44	41	—	—	43	—	—	—	—
mongolica	SIBeria	48	50	46*	50	52	41*	47	—	51*	51	59	—	—	—	—	35*	47*	—
altaica	SIBeria	76	79	71*	83	72	68*	73	—	87*	75	82	62	66	—	65	—	—	—
septentrionalis	FIN NOR SWE	76	78	64*	78	81	76	74	77	87*	76	81*	77	76	77	72	65*	60*	75
rigensis	SWE LATvia	94	96	88*	94	98	92	95	89	101*	95	100	95	99	91	97	84*	83*	—
uralensis	URAL Mtns.	97	100	96	98	94	100	96	90	112*	101	96	—	—	—	85	92*	92*	—
Central European Varieties																			
polonica	POLand	116	110	112	128	117	122	124	—	116	115	108	131	119	108	112	109	97	—
borussica	NE GERmany	121	120	120	123	115	116	121	117	125	123	122	—	127	131	—	123	117	—
hercynica	CZE GER	122	119	123	128*	120	128*	117	126	123	121	120	127	128	120	116	116*	117	107
haguenensis	BEL FRA GER	131	124*	134	147*	123	119	134	148	130	136	123	124	136	137	123	130	127	120
'East Anglia'	ENGland	131	126	128	134	—	—	120	—	140	—	133	—	—	—	134	—	—	—
pannonica	HUNgary	122	98	124	140*	123	114	115	—	126	119	132	—	137	—	98	123	122	—
'N. Italy'	ITAly	111	110	114	118*	—	—	106	—	107	—	112	—	—	—	112	109	112	—
illyrica	YUGoslavia	108	104	115	127	92	100	109	—	103	107	117	—	—	—	112	105	103	—
West and South European Varieties																			
scotica	SCOtland	93	91	84	100	—	—	74	103	100	93	99	—	—	—	93	90	87	—
iberica	SPAin	80	82	87	84*	74	79	82	82	89*	95*	63	56	60	86	71	81	79	72
aquitana	S. FRAnce	92	96	90	96	97	99	89	81	89	104	95	—	78	86	72	91	91	—
rhodopaea	GREece	94	96	92	109*	92	96	92	94	87	99	99*	—	—	—	94	84*	88*	—
armena	USSR TURkey	89	87	92	88	90	90	89	92	88	90	98*	—	—	—	89	86	87	—
Age when measured, years from seed			6	6	6	7	7	6	6	7	5	5	5	5	5	6	6	6	7
Plantation mean height, inches			34	34	24	36	40	34	53	21	21	18	19	21	19	29	30	32	61

[1]) BELgium, CZEchoslovakia, FINland, NORway.

* Differs significantly (5 percent level) from all-plantation average.

survival of 2—1 central European varieties is probably due to an improved root-shoot ratio.

Growth Rate

Between-plantation differences. — Relative growth rates, by variety and plantation, are shown in *table 4.* At the bottom of the table are given average heights at time of measurement. Also included are Iowa data on non-NC-51 plantations from 1964 papers by Gatherum and Jensen.

Growth was most rapid on fertile prairie soils in Iowa and on a moderately fertile sandy loam in central Michigan (plantation 77—61). The last-named plantation received complete chemical weed control for 5 years.

Next best growth (about 30 percent less) was obtained on three dissimilar sites in southern Michigan. One was a nearly level loam receiving chemical weed control on 2-foot strips for the first 2 years. One was a gravel-clay moraine which was furrowed prior to planting. The third was a seemingly infertile loamy sand supporting little but lichens, and receiving no weed control. However, there was a fine, moisture-retaining layer at a depth of 1½ feet.

The slowest growing plantations were on sandy loams in Minnesota, dry cactus-supporting stands in western Michigan, and dry sands and wet clays in northern Michigan. Growth in these places was only 50 percent as great as in Iowa.

Varietal performance at different locations. — In 1962 and 1963, when the trees were 4 or 5 years old from seed, King (1965 a) measured heights of nine NC-51 plantations in Wisconsin, Illinois, and Michigan. Differences among seedlots accounted for 30 percent of the total variance; seedlot × plantation interaction accounted for only 5 percent. In other words, the relative performance of a seedlot remained nearly constant from plantation to plantation.

King's conclusions are still valid for older trees tested over a much wider range of conditions. Central European varieties (especially var. *haguenensis)* grew most rapidly at all sites and northern varieties *lapponica* and *mongolica* grew least at all places.

Height-rank of the varieties remained nearly constant from the nursery to the plantations, as well as between plantations. If anything, the growth-rate differences have increased with age. The ratio of the tallest to the shortest variety was 2.2 at age 2; at the most recent measurements, this ratio varied from 2.5 to 3.3.

Two English seedlots deserve special mention. They came from plantations in East Anglia, England, where there is no native pine. The British tree breeder, J. D. Matthews, thinks the seed originally came from Scotland. An analysis of several growth characters indicates a hybrid origin, with var. *scotica* as one parent and a south European variety as the other. The hybridization probably occurred several generations ago. At ages 5 and 6 they were 31 percent taller than average. This artificial variety illustrates the possibility of inter-varietal hybridization followed by selection.

Another plantation-origin sedlot (MSFG 225 from Boonville, New York) deserves mention. The parent plantation has been used as a seed source by Christmas tree growers. Study of leaf and growth characters shows that it belongs to var. *illyrica* or *rhodopaea,* and that similar growth could be obtained with native Greek or Yugoslav seed.

Several variety × plantation interactions (see asterisks in *table 4)* were statistically significant but were small compared with the main effects. Spanish trees grew exceptionally well (95 percent of plantation mean) at plantation 20—61 on the Keweenaw Peninsula of northern Michigan, probably because of deep snow cover (4 feet or more) which has protected the trees from extreme winter cold.

They also grew exceptionally well at plantation 13—61 in the eastern part of northern Michigan, even though they suffer leader dieback due to cold. Below-average performance in northern Minnesota may be explained as due to extreme winter cold in the absence of deep snow.

It is difficult to explain the excellent growth of var. *rhodopaea* and *armena* from southeastern Europe at plantation 53—61 in central Minnesota.

All northern varieties grew exceptionally well at plantation 13—61 in northern Michigan, poorly in Missouri. It is difficult to explain why their growth at other plantations in Minnesota and northern Michigan was only average, or why it differed so much between two nearby plantations (2—61 and 7—61) in southern Michigan.

Fast-growing var. *haguenensis* was at its best, relative to all others, at plantations 9—61 and 77—61 in southern Michigan. The reason is unknown because these plantations differ markedly in soil fertility and texture, weed control, and average growth rate.

Within-variety differences. — Most varieties exhibited enough variation in growth rate to be of practical interest to a tree planter *(Table 5).*

The variation followed a pattern in the northern varieties *mongolica* and *lapponica* — the slowest growing seedlots were from the northern parts of the variety range. In other varieties there was no apparent pattern — no evidence of elevational or soil races. The random variation is important to a grower wishing the fastest growing seeds. For example, if he wishes growth equal to that obtained with seedlots 237 or 318 of var. *haguenensis* (tallest in the experiment), he must specify that seed be collected from the same stands which furnished those seedlots.

The 10 fastest growing seedlots (relative growth rate 130 percent or more) belonged to three varieties, as follows:

var. *haguenensis* — seedlots 236, 237, 241, 250, 251, 318, 530.
var. *hercynica* — seedlots 526, 529.
var. 'East Anglia' — seedlot 269.

Detailed location data for those parental stands are available on request.

A difference in relative growth rate of 12 percent was needed for a significant (5 percent level) plantation × seedlot interaction. Many interactions were this large. The two fastest growing seedlots of var. *haguenensis* furnish an example. They equal growth rates at plantations 2—61 and 7—61 in southern Michigan. Seedlot 318 grew 14 to 27 percent faster than seedlot 237 in plantations 9—61 (Mich.), 53—61 (Minn.), and 60—61 (Missouri); seedlot 237 grew 14 to 27 percent faster than 318 in plantations 57—61 (Missouri) and 62—62 (Nebraska).

Interactions this large would be of practical significance if a breeder knew why they occurred. Then he could forecast under which conditions 318 would grow best and under which conditions 237 would grow best. However, there was no obvious relation to latitude, soil moisture, care, or soil fertility. Thus, for the present, a grower has only the all-plantation averages on which to base his choice of a particular seedlot.

Autumn Color

Scotch pines of northern origin change from green in summer to red or purple the first winter. In later years the change is from green to yellow. Hacskaylo and Goslin (1957) found that the color change is a light reaction and may be avoided by shading the trees. This is the basis for the commercial practice of cutting and piling Scotch pine in early October. Intensity of color has not been affected by fertilizer applications. Gerhold (1959) found that the color change includes a decrease in chlorophyll and an increase in carotenoids. Steinbeck (1965) found that winter color differences are as evident in dried and ground samples as in freshly collceted needles.

Table 5. — Seedlots which grew at a significantly different rate (5 percent significance level) than the all-variety average.

Variety	Seedlots which grew significantly	
	Slower than average	Faster than average
	Seedlot No.	
lapponica	229	—
mongolica	254	255
altaica	256	—
septentrionalis	230, 545	524
rigensis	542	—
uralensis	258	257
hercynica	203	307, 312, 525, 527, 529
haguenensis	206	237, 318
'Italy'	—	555
scotica	265, 266	268
aquitana	239	—
rhodopaea	272	271
armena	261	—

The reverse change, from winter yellow to summer green has also been studied (White and Wright, 1966). Branches maintained at a daytime temperature of 45° F. or above regained green color in a few days. High temperatures in the absence of light did not result in a color change, and the rate of change was affected very little by night temperature.

Color was measured in terms of live-tree standards, grade 0 being yellowest and grade 9 greenest. The scoring was done from 10 a. m. to 2 p. m., from a distance of 10 to 15 feet. Within-plot variation was ignored. In order to compare the color grades used in different states, representative needle samples were airmailed to Lansing, where they were compared with freshly collected needles. The field scores correlated well with laboratory scores obtained on ground-needle samples compared under fluorescent light. They led to the detection of finer differences than could be recognized by the use of Munsell charts.

Between-plantation comparisons. — King (1965 b) studied color in six NC-51 plantations located in Michigan in 1962 and 1963. The average color difference between plantations was equivalent to 10 percent of the color range within a plantation. Steinbeck (1965) came to a similar conclusion.

In the present experiment the greatest between-plantation difference involved central Michigan plantations within 20 miles of each other.

Needles from plantation 77—61 (loam with complete weed control) averaged two (of ten) color grades greener than needles from plantation 12—61 (dry, loamy sand). The color grades were nearly identical for several plantations in Missouri, Nebraska, Minnesota, and other parts of Michigan.

Varietal differences. — Varieties were ranked nearly the same in all plantations *(table 6).* In all states south European varieties were greenest; Scandinavian and Siberian varieties were yellowest.

Spanish var. *iberica* and French var. *aquitana* were greenest of all. In Nebraska and Missouri the Spanish trees were greener by 1.0 color grade (difference significant at 1 percent level); in southern Michigan the two varieties differed by only 0.1 color grade.

Next greenest were var. *armena* and *rhodopaea* from Asia Minor and the Balkans. They averaged 1.5 grades yel-

Table 6. — Color-rank of Scotch pine varieties at test sites in four North Central states. 1 = the yellowest, 19 = the greenest. Average color-grade is based on scores in five Michigan plantations, 1 = yellow-green, 9 = blue-green.

Variety	Region of	Ave. color grade	Color rank at test sites in									
			Michigan						Minn.	Neb.	Missouri	
			2-61	7-61	9-61	12-61	77-61	13-61	20-62	62-62	57-61	60-61
		grade				*rank*						
		Scandinavian and Siberian Varieties										
lapponica	FIN[1]) SWEden	1.3	2	2	2	3	—	1	—	—	—	—
mongolica	SIBeria	1.1	1	1	1	1	—	1	—	—	2	2
altaica	SIBeria	1.7	4	5	4	2	—	4	—	3	—	—
septentrionalis	FIN NOR SWE	2.0	5	4	5	5	5	5	5	5	5	5
rigensis	SWE LATvia	2.5	6	6	6	6	6	6	6	6	6	6
uralensis	URAL Mtns.	1.4	2	3	3	4	4	2	—	4	1	1
		Central European Varieties										
polonica	POLand	3.8	7	7	7	7	—	7	7	7	7	7
borussica	NE GERmany	5.1	9	8	8	9	9	11	—	—	10	8
hercynica	CZE GER	5.1	8	9	9	8	8	10	9	8	9	9
haguenensis	BEL FRA GER	6.2	12	13	14	11	12	12	12	11	12	13
scotica X ?[2])	ENGland	7.0	17	16	17	11	—	13	—	15	—	—
pannonica	HUNgary	5.5	10	10	11	13	—	8	—	9	8	10
—[3])	ITAly	5.7	14	10	11	10	—	8	—	13	12	11
illyrica	YUGoslavia	6.1	11	13	10	14	—	14	—	12	15	13
		West and South European Varieties										
scotica	SCOtland	6.4	13	11	13	16	14	15	—	—	11	13
iberica	SPAin	8.2	19	19	18	19	19	18	19	19	19	19
aquitana	S. FRAnce	7.9	18	18	19	18	18	18	—	18	17	17
rhodopaea	GREece	6.9	15	13	15	15	17	16	—	16	16	16
armena	USSR TURkey	7.4	15	17	16	16	16	17	—	17	17	18

[1]) BELgium, CZEchoslovakia, FINland, NORway.

[2]) Planted stands believed to have originated from a cross between var. *scotica* and a south European variety.

[3]) The Italian population has not been formally named.

lower than var. *iberica* in Nebraska and Missouri; 1.0 grade yellower in southern Michigan.

Var. *scotica*, from latitude 57° N., comes from the same latitude as southern Sweden and the Ural Mountains. However, it is very much greener than other northern varieties, even surpassing those from central Europe. At one southern Michigan test site it surpassed its hybrid derivative 'East Anglia' in greenness by 1.0 grade; at three other sites in the same state it was surpassed by 'East Anglia' by 0.5 to 1.5 color grades. The interaction is significant at the 1 percent level.

Of the natural varieties from central Europe, fast-growing var. *haguenensis* generally was greenest. At nearly all places it averaged one grade greener than var. *hercynica* from Germany and Czechoslovakia.

Siberian trees were yellowest of all, regardless of where they were tested. With its medium growth rate and good form, var. *uralensis* looked like a good Christmas tree in midsummer. However, by Christmas time every tree was yellow.

Within-variety differences. — Five seedlots were consistently different from others in the same variety. The difference was 0.5 grades or more, the amount needed for significance at the 5 percent level. The exceptional seedlots belonged to var. *septentrionalis, rigensis,* or *hercynica.*

There were relatively few (eight) instances of statistically significant (5 percent level) plantation × seedlot interaction. The most striking involved seedlots 265 and 267 of var. *scotica*. They had grades of 4.2 and 8.2, respectively, in plantation 9—61 on a dry site in southern Michigan but were of nearly the same color at other places. Other striking interactions involved seedlots 222 and 522 of var. *septentrionalis* (Sweden). They differed by 3.6 color grades at plantation 20—62 in Minnesota; by 0.2 or less grades at five places in Michigan.

Needle Length

King (1956b) studied needle length in five Michigan plantations for two years. The year × plantation interaction was very large (31 percent of the total variance), presumably because local moisture deficits caused severe reduction in growth the next year. The seed source component was next largest — 13 percent of the total variance. Seed source × year and seed source × plantation interactions were small, comprising 4 percent of the total variance.

In 1964 new leaf-length measurements were made on two Missouri and two Michigan plantations. They are summarized in *table 7*, which also includes King's data and nursery measurements.

Average needle length in plantation 77—61 was almost 50 percent greater than at any other test site. This was probably due to the excellent moisture relations which resulted from the complete weed control. Better nutrition and water relations are probably responsible also for the extra-long needles found in the nursery. Needles were short in Missouri, probably because of drouth in 1963.

At all places and times var. *haguenensis* had the longest needles and var. *iberica, aquitana,* or *scotica* the shortest. Differences within varieties were not significant.

Site had such an effect that "short-needled" var. *iberica* grown in plantation 77—61 produced longer needles than "long-needled" var. *haguenensis* grown in Missouri. This is important to a Christmas tree grower wishing to produce trees with a definite needle length. A Missouri planter would choose var. *haguenensis* to produce the same type

Table 7. — Differences in needle length associated with variety and place of growth.

Variety	Needle length in: Nursery age 2	Needle length in: 3 Michigan plantations age 4	Needle length age 6: Lansing, Mich. 12-61	Lansing, Mich. 77-61	Missouri 57-61	Missouri 60-61
	millimeters					
Scandinavian and Siberian Varieties						
septentrionalis	56	47	46	65	40	46
rigensis	58	52	56	77	45	47
uralensis	68	52	58	91	50	50
Central European Varieties						
polonica	73	58	70	—	56	54
borussica	75	59	68	89	59	60
hercynica	71	60	66	99	55	55
haguenensis	74	60	79	111	64	62
pannonica	72	60	57	—	59	59
'Italy'	69	52	48	—	44	44
West and South European Varieties						
scotica	49	48	39	81	42	41
iberica	51	43	36	70	35	36
aquitana	50	42	47	56	40	38
rhodopaea	58	52	48	64	41	39
armena	60	54	46	75	43	43

of tree produced with a south European variety in parts of Michigan.

The site effect must also be considered in a breeding program which starts with phenotypic selection in existing commercial plantations. A breeder could make valid comparisons within a single plantation but might not be able to attach much genetic significance to differences between plantations, if each plantation consisted of only a single variety.

Flower Production

Nine seedlings (five of them Belgian) produced pollen when 2 years old. Pollen production was not resumed until the seventh year, when a few trees produced male catkins.

Data on female flowering are available for 10 Michigan plantations. Almost all the flowering occurred in four plantations located south of latitude 43° N. Few flowers were found on six more northerly plantations. Daylength was probably responsible for the difference.

In the four southern Michigan plantations, female strobili appeared first in 1963, age 5 from seed. There were 9 flowering trees in 1963, 129 in 1964, and 838 in 1965. Corresponding numbers of conelets were 15, 325, and 5,011.

There was a general relationship between growth rate and flowering. The three tallest varieties ('East Anglia', *haguenensis, hercynica)* produced conelets on 19, 15, and 11 percent of the trees, respectively, at age 7. Corresponding figures for the three shortest varieties were 1, 0, and 2 percent. There was also an important exception to the general trend. Flowers occurred on 12 percent of the trees of French var. *aquitana;* this was significantly more than on northern varieties with faster growth rates.

The two fastet growing seedlots, both belonging to var. *haguenensis,* exhibited strong differences in flowering behavior. Three percent of the trees of No. 237 flowered, in contrast to 34 percent of the trees of No. 318. There were also differences within var. *armena.* The proportion of flowering trees was 1, 1, 2, and 4 percent for four Turkish seedlots; 2, 10, 17, and 23 percent for four seedlots from the Caucasus Mountains of southern Russia. In both varieties the within-variety differences were significant at the 1 percent level.

Steinbeck's (1965) data furnish a possible clue to the within-variety differences. The heaviest flowering occurred on seedlots low in Na, high in Fe and Al. There was no apparent relation to content of 9 other elements.

Winter Injury

Var. *iberica.* — Spanish trees suffered the most winter injury. Usually this took the form of needle browning, with no apparent damage to the growing point. Such trees appeared to grow normally the next season, but may have suffered reduced height growth. A few very cold sites had trees on which the leaders were killed.

At first it was assumed that the injury occurs during very cold weather in midwinter when the ground is frozen. However, it is possible that the damage occurs during the hardening off period in autumn. That was the indication from injury observed at plantation 12—61 (southern Michigan) in mid-December 1965. The damage, which was confined to a low spot, occurred before the ground froze and before temperatures became as low as 20° F.

Table 8 shows the variations in damage to var. *iberica* during two winters. In general the damage was heaviest on northern sites without deep snow cover. Also it seemed to be heavy following a late summer drouth, as at plantation 11—61.

Data for five Spanish seedlots included in the three most heavily damaged plantations were subjected to analysis of variance. The differences among seedlots were not significant.

Michigan Christmas tree growers have planted var. *iberica* extensively because of its color and slow growth. Most of these commercial plantations are located on light-textured soils along Lakes Michigan or Huron, where snow cover is usually heavy. Winter burn has varied from none to moderate and the variety is still recommended.

The consistently severe needle and bud injury to var. *iberica* in Minnesota plantations indicates that such sources should be avoided by growers in the northern and central parts of that state. No test plantations are located in the southern counties.

Table 8. — Percent of Spanish trees (var. *iberica*) damaged at various test sites during the 1963—64 or 1964—65 winters.

State	Plantation No.	Trees damaged	Type of damage, site conditions
		percent	
Minn.	4 plantations	100	Brown lvs., dead leaders, cold sites
NW Ill.	39—61	62	Brown lvs., sandy loam, little snow
Cent. Mich.	10—61	62	Brown lvs., dead leaders, sandy snow with light snow cover
SW Mich.	11—61	58	Brown lvs., sandy soil, medium snow cover
N. Mich.	13—61	13	Dead leaders above snow level, moist site
Cent. Mich.	22—61	8	Brown lvs., exposed sandy site
N. Mich.	21—61	0	Loam, heavy snow cover
Cent. Mich.	8—62	0	Sandy soil, light snow cover
SW Mich.	4 plantations	0—3	Sandy to loam soils, light to moderate snow cover
Missouri	5 plantations	0	Commercial plantings also damage-free

Var. *aquitana.* — In plantations where var. *iberica* was severely damaged, trees from France's Central Massif have suffered some winter injury in plantation 39—61 (NW Illinois), where 14 percent of the trees suffered slight needle browning. During the 1964-65 winter slight injury was reported on 0 to 4 percent of the trees in Michigan plantations.

Var. *rhodopaea* and *armena.* — Two to 3 percent of the trees of these varieties suffered slight needle browning in Michigan during the 1964-65 winter. Damage was confined to the three plantations with the most damage to var. *iberica.*

Other varieties. — Other varieties suffered little or no winter injury.

Susceptibility to Insect Attack

Natural insect infestations were high enough to give useful information on resistance to four insect pests. The details are being published elsewhere in papers by WRIGHT *et al.* (1966 a, 1966 b).

With each of the four insects one or more Scotch pine varieties was significantly more resistant to attack than were others. However, complete resistance was not found. The mechanism seemed to differ in each case.

Correlation analyses were used to study the resistance mechanisms. They gave clues, but only clues. In each case the resistant and susceptible varieties differ in so many respects that it has not been possible to prove which factor(s) was responsible for the differences in feeding.

European pine sawfly *(Neodiprion sertifer* [GEOFF.]). — Sawflies attacked four southern Michigan plantations during the years 1963 to 1965. The percentage attack varied from 1 to 29 percent. The relative susceptibility of each Scotch pine variety remained constant from year to year and place to place.

There was a statistically significant (0.1 percent level) relation between seedlot height and percent attack — taller origins were attacked most. For the central European varieties, percent attack = $-32.8 + .865$ (height in inches), and $r = .816$ with 29 d. f.

There were also significant exceptions to the general trend. All seedlots of var. *uralensis* were attacked much less than expected for their height. This was very noticeable in the field, where a var. *uralensis* plot was nearly always (95 percent of the time) attacked less than a neighboring plot of similar size. Var. *iberica* was attacked much more than expected for its height *(Table 9).*

The resistance of var. *uralensis* is possibly related to its wider needles, earlier development of autumn color, or foliar content of N, P, K, Na, Mg, Fe, B, Zn, or Al. In all these traits the variety differed from more susceptible ones.

White-pine weevil *(Pissodes strobi* [PECK]). — In 1964 a heavy infestation of white-pine weevil occurred in plantation 10—61 near Higgins Lake in central Michigan. The infestation was also repeated in 1965. During the two years 95 percent of the trees of some seedlots were attacked.

This insect is known to favor the tallest trees of eastern white pine. There was some evidence that this was also true in the Scotch pine — the four slowest growing northern varieties suffered much less attack than the fast-growing central European varieties *(Table 9).*

Seedlot 210 (var. *hercynica)* offered the best evidence that susceptibility to attack was influenced by genetic factors other than growth rate. It had an average height of 44 inches and an attack percent of 35. From 55 to 100 percent of the trees were attacked in other seedlots having heights

Table 9. — Varietal differences in susceptibility to attack by four insect pests.

Variety of Scotch pine	Percent of trees attacked by			
	European-pine sawfly	White-pine weevil	Jack-pine budworm	Pine webworm
	percent			
Scandinavian and Siberian Varieties				
lapponica	0.2	12	39	—
mongolica	1.1	20	52	0.0
altaica	.9	45	21	—
septentrionalis	2.4	57	43	.0
rigensis	6.1	76	46	1.2
uralensis	3.2	86	34	.0
Central European Varieties				
polonica	19.1	77	80	.0
borussica	20.6	41	55	.0
hercynica	19.5	80	54	1.9
haguenensis	25.7	65	42	1.1
'East Anglia'	26.5	—	—	—
pannonica	20.1	97	25	10.0
illyrica	18.7	68	54	10.0
'Italy'	11.6	—	—	3.8
West and South European Varieties				
scotica	6.5	—	—	7.5
iberica	10.6	15	22	7.0
aquitana	9.6	72	23	2.0
rhodopaea	9.3	72	38	10.0
armena	6.7	46	35	10.0
Years observed	3	2	1	1
Plantations observed	4	1	1	1
F value, Variety	5.02**	5.11**	4.47**	6.23**
F within Variety less than 1		2.44*	1.42*	1.32

of 41 to 46 inches. The differences were significant at the 1 percent level.

Jack pine budworm *(Chloristoneura pinus* FREEMAN). — An epidemic of budworm occurred on jack pine over a large area of central Michigan in the summer of 1965. Plantation 10—61 was in the center of the epidemic and was heavily infested *(Table 9).* However, damage to the Scotch pine was slight.

Of the total variance in incidence of attack, 57.0 percent was due to variety, 35.3 percent to error, 5.5 percent to location within planting, and 2.2 percent to variation among seedlots within varieties. French var. *aquitana,* Spanish var. *iberica,* and Siberian var. *altaica* had the lowest number of attacks, averaging 22, 23, and 21 percent respectively. Only one of the 10 seedlots comprising these varieties had as much attack as did any of the 30 central European seedlots in the plantation.

There was one striking example of differences among seedlots belonging to the same variety. MSFG 254 was shortest (14 inches in 7 years) and suffered next to the most attack (89 percent of the trees); MSFG 255 was fourth from smallest (22 inches) and suffered next to the least attack (14 percent of trees). This difference is responsible for most of the within-variety variance.

Pine webworm *(Tetralopha robustella* ZELL.). — Missouri plantation 60—61 had a light infestation of pine webworm in 1964. Five percent of the trees were attacked. Varieties from southern Europe were most susceptible *(Table 9).* Slow-growing ones from northern Europe and fast-growing trees from central Europe were attacked very little.

Abstract

A range-wide provenance test of Scotch pine was started in 1959 with seeds from 108 native and several planted stands. The seedlings were grown for 2 years in central

Michigan and planted at 31 permanent locations in 8 north central states. The field tests follow a randomized complete block design with 4 to 10 replicates and 2- to 4-tree plots.

Mortality per plantation ranged from 3 to 80 percent, mostly due to differences in care. In all plantations established with 2−0 stock, morality was lowest for varieties from Spain, southern France, and southern Scandinavia; highest for varieties from central Europe and the far north.

Height at age 5, 6, or 7 was measured at 16 test sites in 5 states. Differences between plantations and between varieties were large; plantation × variety interaction was small in most cases. Trees of var. *haguenensis* (Belgium, N. France, western Germany), var. 'East Anglia' (England), and *hercynica* (Germany, Czechoslovakia), grew fastest. Trees of var. *lapponica* (northern Scandinavia), *mongolica* (Mongolia, eastern Siberia), and *altaica* (Altai Mountains of Siberia) grew only ⅓ as fast.

Scandinavian and Siberian varieties turned very yellow during the winter. On the other hand, trees from Spain, southern France, the Balkans and Asia Minor remained green. Central European varieties were intermediate. The intensity of winter color varied little from plantation to plantation, being nearly the same in Missouri and Nebraska as in Minnesota and Michigan.

Needles were longest in central European varieties and shortest in varieties from southern Europe. In almost every plantation the needles of var. *haguenensis* were twice as long as were those of var. *iberica.* There was relatively little plantation × seedlot interaction although there were important differences among plantations. Needles were twice as long at one test site as at another. The longest needles occurred in a plantation which had received complete weed control and which grew the most rapidly.

Winter injury was almost confined to Spanish var. *iberica.* They suffered moderate to heavy damage at seven plantations in Minnesota, Michigan, and northwestern Illinois; little or no damage at nine other plantations in Missouri, Nebraska, Iowa, and Michigan. In most cases the injury consisted of needle browning, with no apparent damage to cambium or growing point. On very exposed sites the leaders were killed. The damage pattern was anomalous in many respects.

Production of female flowers started at age 5 and increased steadily until age 7. Production was heaviest on four Michigan plantations south of latitude 43° N; nil on six more northerly test sites. In general, the tallest seedlots flowered most. However, there were important exceptions within var. *haguenensis* and var. *armena* — seedlots which grew at the same rate but differed significantly in percent of flowering trees. The most heavily flowering seedlots were low in Na, high in Fe and Al.

Natural infestations offered opportunity to study differences in susceptibility to attack by four insects. Var. *uralensis* was most resistant to attack by the European pine sawfly. The results were consistent for three years at four different sites. Var. *iberica* was least attacked by the white-pine weevil during a 2-year infestation of one plantation. There was a slight relation between variety and amount of attack (southern varieties attacked least) by the jack pine budworm during a 1965 infestation of a plantation in central Michigan; however, the most striking differences (14 vs. 89 percent of trees attacked) were between two seedlots of var. *mongolica.* During a 1964 pine webworm infestation in Missouri, 5 to 10 percent of the trees were attacked in southern varieties; 0 to 2 percent of the trees of central and northern varieties.

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