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ABSTRACT — Scotch pine exhibits clinal variation from north to south in two characteristics: viz., the number of days after April 15 to the time of maximum rate of height growth, and total height after the age of 17 years. There is east-west clinal variation with respect to two characteristics: viz., the number of days after April 15 to the beginning of height growth, and to the time of the maximum rate of height growth. The twelve out of the fifteen varieties analyzed showed the existence of valid sub-varieties or ecotypes. Varieties from central Europe were the fastest growing in each of four planting sites in Minnesota. Significant mortality was noticed among the seed sources from the 40°-45° N. latitudinal class, in six outplantings. Production of lammas shoots was found to be under strong environmental influence. The seed sources from the 50°-55° N. zone were found to be the most highly susceptible to attack by the white pine weevil (*Pissodes strobi* Peck.).

Scotch pine (*Pinus sylvestris* L.) is the most widely distributed pine species of the world, occupying extensive tracts in Europe and Asia between latitudes 40° and 70° N. and longtitude 10° W. and 140° E. The species exhibits considerable morphological and physiological variation, which has been recognized and studied since 1865 when De Vilmorin first published the results of provenance trials conducted at Des Barres (De Vilmorin, 1865).

The present research was conducted to study the following problems with reference to variation in Scotch pine:

1. Nature of variation with respect to physiological processes exhibited in the phenology of height growth. Specifically, the objective was to determine whether this variation was chiefly continuous (clinal), or discontinuous (ecotypic).
2. If the variation was discontinuous to determine if the varieties into which the species has been lately divided by Ruby (1964) are homogeneous or heterogeneous.
3. Performance of the different varieties and provenances in Minnesota.

Study in Six Plantings

The present studies were conducted in the six outplantings of *Pinus sylvestris* made by the North Central Cooperative Regional Research Committee under the NC-51 Project, entitled "Tree Improvement through Selection and Breeding." These outplantings grown from a range-wide seed collection were established by the School of Forestry, University of Minnesota, at Blackberry (1962 and 1964), Cloquet (1962 and 1964), North Branch (1962) and Rice (1961). The plantations have different numbers of provenances, five or ten replications, and all are arranged in a randomized complete block design, including four-tree plots and one or two border rows around each plantation.

Field Work

The field work consisted of periodic measurements of the length of the current year's shoot on all trees in the six plantations at approximately weekly intervals. This work was conducted in the growing season of 1966, and the following statistics were computed:

Number of days after April 15 to the commencement of height growth.

Number of days after April 15 to the time of the maximum rate of height growth.

Number of days after April 15 to the cessation of height growth.

A regression equation was established for each seed source, showing the relationship of the number of days after April 15 (X) and the length of the shoot (Y). The best fitting equation was found to be:

$$Y = a + b \log X.$$

The data for the number of days after April 15 (X) and the length of the shoot at weekly intervals (Y) were then programmed for a University of Minnesota IBM 360/30 computer. The following statistics were obtained from the computer output.

The intercept of Y on X (a).

The coefficient of regression of Y on X (b).

Total heights of each tree from 1961 through 1966 were measured and averaged by provenances.

Trees were also scored for survival in 1966, for lammas shoots and damage by the white pine weevil (*Pissodes strobi* Peck.) in 1966.

The Nature of Variation

The controversy about the nature of variation in Scotch pine started with the publication by Wright and Baldwin (1957) of the results of the International

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Union of Forest Research Organizations provenance studies of 1938 in New Hampshire. They conducted analyses of variance of seven qualitative and three quantitative traits on the basis of which they concluded the presence of discontinuous, non-clinal or ecotypic variation in the species, the ecotypes being latitudinal. However, the results of Langlet (1959), based on the correlation analyses of the dry weight of 2-0 and 2-2 seedlings and 17-year height, showed that the variation was clinal or continuous. Correlation analysis of the data of Wright and Baldwin (1957) and that of Schreiner *et. al.* (1962) by me showed that the variation in the percentage of trees with large crooks, cones and lean was discontinuous or ecotypic, while that for the percentage of dry matter in needles and the average height and average diameter at the age of 18 years showed clinal variation with latitude.

The data also were analyzed by correlation analysis. Coefficients of correlation were calculated for each of the above mentioned characters and the three geographical factors of the origin of the relevant provenance, *viz.* latitude, longitude and altitude. The results are summarized in Table 1.

These results support the following conclusion:

1. There is clinal variation with latitude with respect to the number of days after April 15 to the time of the maximum rate of height growth and with total height. But correlation between latitude and total height disappears as the trees grow older. Correlation analysis between latitude and height at 17 years, based on the data of Wright and Baldwin (1957) has shown that there is clinal variation in height with latitude. Similar conclusions are available from the correlation analysis of the data of Schreiner, *et. al.* (1962). This suggests that clinal variation reappears at or about the age of 17 years.
2. There is clinal variation with longitude with respect to two characters. *viz.* the number of days after April 15 to the commencement of height growth and to the time of the maximum rate of height growth. There is no clinal variation with respect to any other character.
3. There is no clinal variation with altitude with respect to any character.

Status of Varieties

The characters mentioned above were then analyzed by analyses of variance, followed by Duncan's multiple range tests for both the between—varieties and within-variety variances.

Out of the 19 varieties available in Minnesota, only 15 could be further analyzed for within variety variances. It was found that the varieties as recognized by Ruby (1964) were valid based on the physiological responses to the environment studied.

Nine of these fifteen varieties appear to be uniform in growth characters and cannot be further sub-divided into sub-varieties or ecotypes on the basis of the information available from the seed sources tested. These varieties are homogeneous, usually with non-significant differences between seed sources within varieties. They are: *altaica, aquitana, borussica, carpatica, hercynica, iberica, lapponica, polonica* and *uralensis.* The tenth variety, *viz., haguenensis,* possibly has a Belgian ecotype significantly different from a German ecotype. The eleventh variety, *viz., septentrionalis* has a large, randomly distributed within variety component of variance. This variety has a large proportion of significantly different pairs of seed sources, which cannot be grouped into any distinct geographic pattern.

The remaining four varieties, *viz. armena, rhodopaea,*

TABLE 1. Results of correlation analyses.

Character	Value of Student's t																	
	Latitude						Longitude						Altitude					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1. Number of days after April 15 to commencement of height growth.	NS	NS	NS	**	NS	**	NS	**	*	**	NS	**	NS	NS	**	*	NS	NS
2. Number of days after April 15 to the time of maximum rate of height growth.	**	NS	**	NS	*	**	NS	*	NS	**	NS	*	NS	NS	NS	NS	NS	NS
3. Number of days after April 15 to cessation of height growth.	NS	NS	**	NS	**	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
4. Intercept of Y on X (a).	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
5. Coefficient of Y on X (b).	**	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
6. Total height in 1961.	**	A	**	A	**	**	NS	A	NS	A	NS	NS	NS	A	NS	A	NS	NS
7. Total height in 1962.	**	A	**	A	**	**	NS	A	NS	A	NS	NS	NS	A	NS	A	NS	NS
8. Total height in 1963.	**	NS	*	**	**	*	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	*
9. Total height in 1964.	*	NS	NS	NS	*	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	*
10. Total height in 1965.	*	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	**
11. Total height in 1966.	*	NS	NS	NS	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	*	NS	**

A = Plantation absent.
NS = Non-significant at the 0.05 level.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.

1. = Blackberry 1962 plantation.
2. = Blackberry 1964 plantation.
3. = Cloquet 1962 plantation.
4. = Cloquet 1964 plantation.
5. = North Branch plantation.
6. = Rice plantation.

rigensis and *scotica* appear to be divisible into geographically distinct ecotypes as shown below:

Variety *armena*: Two ecotypes, *viz.*, one covering northeastern Turkey, Georgian S.S.R. and Bulgaria and the other occupying Rumania.

Variety *rhodopaea*: Two ecotypes, *viz.*, (1) from Czechoslovakia and southern Bulgaria and (2) from the mountains of northern Greece.

Variety *rigensis*: Three ecotypes, occupying three different latitudinal zones, *viz.*, latitudes 55°N., 57°N. and 58°N.

Variety *scotica*: Two ecotypes, *viz.*, (1) from Scotland and (2) from England, distinguished by some authors as "East Anglia."

Performance in Minnesota

The following criteria were used for measuring the relative performance of Scotch pine provenances at various locations in Minnesota.

1. Rate of height growth as indicated by the value of the coefficient of regression of Y on X (b) and the total height in 1966.
2. Survival till 1966.
3. Lammas shoots.
4. Susceptibility to the white pine weevil (*Pissodes strobi* Peck.) The results of statistical analysis of these measurements are discussed below.

The results of the between-varieties analyses of variance for b and total height are summarized in Table 2.

These results show that varieties are a highly significant source of variation with respect to these two characters at all locations. Duncan's multiple range tests and within variety analysis of variance showed that the following varieties were the fastest growing at the different locations:

Blackberry — Varieties *hercynica, haguenensis, polonica, borussica* and *vindelica,* all from central Europe.

Cloquet — Varieties *polonica, borussica, hercynica,* and *carpatica* from central Europe. Out of these, variety *polonica* is represented by only one seed source and *borussica* and *carpatica* are homogeneous. In the variety *hercynica* the fastest growing seed sources are numbers 204, 208, 306 and 312, from southern Germany and Czechoslovakia.

North Branch — *Varieties borussica and haguenensis,* from central Europe, both of which are homogeneous.

Rice — Varieties *borussica, haguenensis, hercynica* and *polonica* from central Europe. The fastest growing seed sources within these varieties are:

Variety *borussica.* Seed source 210 from northeastern German lowlands.

Variety *haguenensis.* Seed sources 235, 236, 241, 251, 252, 318 and 530 from eastern France, western Germany and Belgium.

Variety *polonica.* Seed sources 211 and 317 from Poland.

Variety *hercynica.* Seed sources 204, 208, 305, 306, 525, 527 and 528 from southeastern Germany and Czechoslovakia.

In the Blackberry 1962 plantation mortality was practically confined to provenance 219 from Spain (latitude class 40°-45° N.) in which there was considerable mortality in each location due to frost.

Mortality appears to be randomly distributed in all the five degree latitude classes in the Blackberry 1964 plantation. However, the mortality was highest in the latitude class 40°-45° N. in which case as many as 75 percent seed sources had casualties in three or more replications out of five.

In the Cloquet 1962 plantation the highest casualties were in the provenances 218 and 219, both from Spain in the latitude class 40°-45° N. Both these seed sources had casualties in each of the five replications studied. There were significant casualties in the provenances from the latitude class 60°-over N. in which at least one seed source out of four, *viz.* number 233 had casualties in four replications out of five.

Also in the Cloquet 1964 plantation, the variation due to replications is highly significant. This is due to the high incidence of damage by rabbits in the northern part of the plantation. However, the highest mortality was noticed in the provenances from the latitude zone 40°-45° N., in which two seed sources, (*viz.* 220 and 613 from northeastern Turkey and southern Bulgaria,

TABLE 2. Results of analyses of variance and Duncan's multiple range tests between varieties for b and total height in 1966

Location	Coefficient of regression of Y on X		Total height in 1966	
	F	P	F	P
Blackberry 1962 plantation	41.43 **	71	12.22 **	75
Blackberry 1964 plantation	9.69 **	42	12.81 **	60
Cloquet 1962 plantation	20.73 **	64	45.90 **	69
Cloquet 1964 plantation	17.62 **	65	30.40 **	62
North Branch plantation	45.25 **	73	48.16 **	82
Rice plantation	20.40 **	63	11.28 **	46

F = Snedecor's F ratio for varieties.
P = Percentage of significantly different pairs of varieties at the 0.05 level.
** = Significant at the 0.01 level.

TABLE 3. Summary of the analyses of variance of the trees Surviving till 1966

Location	Snedecor's F ratio	
	For replications	For provenances
Blackberry 1962 plantation	0.00 NS	43.67 **
Blackberry 1964 plantation	0.00 NS	2.67 **
Cloquet 1962 plantation	0.00 NS	5.43 **
Cloquet 1964 plantation	2.63 **	2.89 **
North Branch plantation	4.31 **	3.03 **
Rice plantation	0.97 NS	1.51 **

respectively), out of ten had some mortality in three or more replications out of five.

The casualties in the North Branch plantation were mainly due to gophers, and are random as regards seed sources.

The mortality at Rice was caused by the delay in transportation time from the nursery and was random. However, the latitude class 40°-45° N. had the greatest number of seed sources with casualties in three or more replications out of five.

Table 4 shows the results of analyses of variance of the number of trees with lammas shoots at each location.

TABLE 4. Summary of the analyses of variance of the number of trees with lammas shoots in 1966

Location	Snedecor's F ratio	
	For replications	For seed sources
Blackberry 1962 plantation	0.00 NS	1.00 NS
Blackberry 1964 plantation	1.39 NS	1.50 NS
Cloquet 1962 plantation	0.00 NS	1.29 NS
Cloquet 1964 plantation	0.00 NS	0.87 NS
North Branch plantation	1.67 NS	2.69 **
Rice plantation	1.14 NS	1.82 **

NS = Non-significant at the 0.05 level.
** = Significant at the 0.01 level.

These results show a non-significant variance due to replications, which indicates homogeneous edaphic and micro-climatic conditions within each plantation. The variation due to seed sources is non-significant at the four northern locations but highly significant at the two southern ones, suggesting that production of lammas shoots is under strong environmental influence.

Susceptibility to White Pine Weevil (*Pissodes strobi*)

A mild attack by the white pine weevil (*Pissodes strobi*) in the Cloquet 1962 plantation afforded an opportunity to study the susceptibility of Scotch pine provenances to its attack. On grouping of the affected trees, damage was found to be restricted to six varieties only, *viz. haguenensis, hercynica, mongolica, polonica, rigensis* and *septentrionalis*. By grouping the damaged trees in latitude classes, the damaged trees were distributed as shown in Table 5.

These results show that the trees from the region 50°-55° N. were the most seriously affected.

White pine weevil has been known to attack vigorously-growing dominant white pine trees with relatively a larger proportion of cortex than the dominated trees. The fastest growth rate and the greater vigor of the trees from central Europe may be the reason for a greater incidence of damage in these trees than those from the northern and southern regions.

TABLE 5. Distribution of white pine weevil damage in the five latitude classes in 1966

Five degree latitude classes	Percentage of damaged trees
40°-45° N.	0
45°-50° N.	8
50°-55° N.	25
55°-60° N.	7
60°-over N.	14

Conclusions

1. Clinal variation with latitude was detected only for the number of days after April 15 to the time of the maximum rate of height growth and for total height in the early and late years.

2. There is clinal variation with longitude with respect to two characters, *viz.* the number of days after April 15 to the commencement of height growth and to the time of the maximum rate of height growth.

3. Clinal variation with altitude does not exist with respect to any character.

4. Eight varieties were found to be homogeneous and not further divisible into ecotypes or sub-varieties. Three provenances had a high within variety component of variance.

5. Results from the Blackberry and Cloquet outplantings show that six varieties from Central Europe are among the fastest growing for northern Minnesota. These are: *borussica, carpatica, haguenensis, hercynica, polonica,* and *vindelica.* The variety *rigensis* from the Latvian S.S.R. in northern Europe is also promising for this area. Similarly, four varieties, *viz. borussica, haguenensis, hercynica* and *polonica* from central Europe have been found to be the fastest growing varieties in central Minnesota on the basis of their superior performance at North Branch and Rice.

6. Casualties were mostly due to pests, rather than to seed sources.

7. Six varieties, *viz. haguenensis, hercynica, mongolica, polonica, rigensis* and *septentrionalis* are susceptible to attack by the white pine weevil (*Pissodes strobi*). The damage is highest in the provenances from the central zone, medium in the northernmost seed sources and is lowest in the southern provenances.

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