Variation in Growth and Branching Characters in Black Pine (Pinus nigra Arnold) of Peloponnesos

By D. I. MATZIRIS[1])

(Received 7th April 1986)

Summary

In a black pine (*Pinus nigra* ARNOLD) seed orchard, comprising 52 clones selected from the natural forest of Peloponnesos, Greece, the following 16 growth and branching characters were studied: tree height, length of terminal shoot, number of lateral buds, number of branches, branch length, branch thickness and branch angle in the first, second, and third whorl, as well as crown diameter.

For all characters there exist significant clone differences. The length of terminal shoot varied from 42 cm to 74 cm (overall mean 55cm); the corresponding number of lateral buds was 3.3 and 7.1. The branch angle increases with whorl number (age), while the number of branches decreases. Correlation coefficients (phenotypic) are variable, with the highest value (0.82) found between branch length of the third whorl and crown diameter. Repeatability values on individual tree and clone mean bases were estimated. In all cases branch length was found to be stronger genetically controlled than branch thickness. The values increase with whorl number (age).

Key words: Seed orchard, *Pinus nigra*, repeatability, correlation.

Introduction

Black pine (*Pinus nigra* ARNOLD) is one of the most important coniferous species native to Greece and it is extensively used in reforestation. There are four main advantages for its extensive use: i) it is well adapted to a large range of environmental conditions forming different populations. BASSIOTIS (1967) has recognized three ecotypes. The more drought resistant grows in the southern Part of Greece (population of Peloponnesos). The second grows in the Pindos mountain range and the third grows in the northeast of the country. ii) it is not a highly demanding species and can grow even on degraded land, iii) it can compete successfully, at a young age, with other natural vegetation and therefore it is easily to establish even with minimal care, and, iv) it grows quite rapidly producing good quality wood, which has a high demand.

The importance of the genetic quality of the seed used in the reforestation programs of Greece, has been emphasized by MATZIRIS (1978a), and clonal seed orchards were establshed (MATZIRIS, 1987b; PALMBERG, 1983). Variation in a number of morphological and anatomical needle characters of the population of Peloponnesos was observed in an earlier study (MATZIRIS, 1984).

The purpose of this investigation is to study the variation of 16 growth and branching characters in the clonal seed orchard of Koumani, Peloponnesos, at the age of five years from the time of establishment, to estimate repeatability values for all characters and to estimate the magnitude of the interrelationship among all combinations of the characters.

[1]) Forest Research Institute, Forest Genetics Section, Terma Alkmanos, Athens 115 28, Greece

Material and Methods

Plant material

In October 1978 an 11 ha black pine seed orchard was established at Koumani, Peloponnesos, comprising 52 clones with a total number of 2700 grafts. Grafts were two years old at the time of establishment and were planted at a spacing of 6 $\times$ 6 meters. The 52 plus trees were selected in the natural forest of Peloponnesos on the basis of many economically important characters. Details concerning selection, grafting and establishment of the orchard are given elsewhere (MATZIRIS, 1978b, 1982).

Before planting the area of the seed orchard was covered by high forest of *Quercus conferta* KIT. (*Quercus frainetto* TEN.). It is located in the north west part of Peloponnesos within the bioclimatic zone of Meso Mediteranean, which is characterized by 40 to 75 biological dry days (MAVROMMATIS, 1980). The mean annual precipitation is quite high (1570 mm), but the rain is not well distributed over the year. July is the driest month, with a mean rainfall of 14 mm followed by August with 24 mm. The soil has developed from Tertiary deposits, is clay loam, moderately acid with an adequate supply of metallic cations and organic matter (NAKOS, 1979).

Measurements

In each ramet the following 16 characters, tree height, length of terminal shoot, number of lateral buds, number of branches, branch length, branch thickness and branch angle in the first, second and third whorl, as well as crown diameter were measured or counted and analysed. The thickness of the branches was measured at a distance 5 cm from the main stem, because of swellings observed in the proximity of the stem. The whorls were numbered consistently from the top downwards so that no. 1 was the youngest whorl and no. 3 was three years old.

Statistical Evaluation

For each character an analysis of variance was made, following standard-procedures as outlined e.g. by SNEDECOR and COCHRAN (1967) or BECKER (1967). The general form of analysis used is shown in *Table 1.*

The variance between clones (σ^2_c) was interpreted as:

Table 1. — General form of the analysis of variance.

Source of variation	D.F.	M.S.	E(M.S.)
Between clones	C-1	M_1	$\sigma^2_w + n_o\sigma^2_c$
Between ramets within clones	$\Sigma(n_i-1)$	M_2	σ^2_w

C = number of clones = 52

n_i = number of ramets in i^{th} clone

σ^2_c = variance due to differences between clones

σ^2_w = variance due to differences between ramets

$$n_o = (\Sigma n_i - \frac{\Sigma n^2_i}{\Sigma n_i}) \frac{1}{C-1}$$

$$\sigma^2_c = Cov(X,Y) = \sigma^2_G + \sigma^2_{CL}$$

Where: X, Y are ramets of the same clone, σ^2_G is the total genetic variance within the population and σ^2_{CL} is the cloning effect variance due to vegetative propagation (SHELBOURNE, 1969).

According to WILCOX (1974) this represents the covariance among ramets and among other sub-samples of the same clone due to common physiological age and other non-genetic similarities carried from the ortet by cloning. As the cloning effect variance is confounded with the genetic variance (σ^2_G), part of the clonal variation may be due to variation in ortet age. Because the age differences of the selected ortets were small it is assumed that the cloning effect variance can be ignored.

The variance between ramets within clones (σ^2_w) is a measure of the environmental variance. This is also not an absolute interpretation, since some of the variation could have arisen from differences among the root-stock. Because the root-stock used was rather uniform and randomly assigned to the scions it is assured that its influences were of minor importance.

Repeatability (R), which measures the correlation between repeated measurements of the same clone, was estimated as the ratio of clonal variance to total phenotypic variance.

Because of the uncertain interpretation of the clonal variance, R should be considered as an upper limit of the broad sence heritability (FALCONER, 1960, page 146; WILCOX, 1974).

Two measures of R each with different phenotypic variance were computed:

$$R_1 = \frac{\sigma^2_c}{\sigma^2_c + \sigma^2_w} \text{ (individual tree basis)} \qquad R_2 = \frac{\sigma^2_c}{\sigma^2_c + \sigma^2_{w/no}} \text{ (clone mean basis)}$$

The standard error of (R_1) was also computed using the following formula given by SWIGER *et al.* (1964).

$$S.E.(R_1) = \sqrt{\frac{2(n.-1)\,(1-R_1)^2\,[1 + (n_0-1)\,R_1]^2}{n^2_0\,(n.-C)\,(C-1)}}$$

Where: n. = total number of observations = 1 033

n_0 = Coefficient of the component σ^2_c = 19.86

C = number of clones = 52

It should be further mentioned that, since the parent trees were selected, the genetic parameters estimated should refer to the selected population only and not to the whole population of the black pine of Peloponnesos.

Results and Discussion

The mean values for each clone for the 16 characteristics are given in *Table 2* and are discussed below.

Height and Length of Terminal Shoot

The total tree height varied among clones from 146 cm (clone 40) to 238 cm (clone 6). The differences were statistically significant. Clone 6 originated from the northern part of Peloponnesos (Zaruchla), while clone 40 was selected in the southern part (Teygetos mountain). Clone 45, with rank 3, was also selected in Taygetos.

Considerable variation was also observed among clones in the length of the terminal shoot, which represents the growth of the year 1983. Mean values ranged from 42 cm (clone 32) up to 74 cm (clone 45). Clone 6 had a mean length of the terminal shoot of 66 cm. Since the trees were not fertilized a mean annual growth of 55cm is considered very satisfactory. All grafts were healthy and physiologically very active.

Lateral Buds and Number of Branches

The number of lateral buds varied among the clones. The overall mean of the 52 clones was 5.2 with a range between clone means from 3.3 (clone 10) to 7.1 (clone 26). Large variation was also observed in the number of branches. In the first whorl the mean number of branches was 4.8 with a range among clone means from 3.4 to 6.3 and a coefficient of variation of 20.8 percent. The number of branches found in the second and third whorl were smaller (*Table 2*). As the number of branches is higher in the first whorl and decreases with increasing number of whorl, it seems that some of the young branches are aborted. There is also indication that not all of the lateral buds develop into branches. A similar reduction of the number of branches from the top of the tree downwards was also reported for a young progeny test (EHRENBERG, 1963) and for grafted clones of Scots pine (HATTEMER *et al.*, 1977). EHRENBERG found the number ol branches in whorl two to be about half that in whorl one.

Branch Length and Thickness, Crown Diameter

The length and thickness of the branches per clone and whorl are shown in *Table 2*. The analyses of variance showed that significant differences among clones exist for all characters. The results are in agreement with previous research reported by HATTEMER *et al.* (1977) in young clones and EHRENBERG (1963) in a progeny test of Scots pine.

Crown diameter is a function of branch length and branch angle and is considered an important character both from the silvicultural as well as the genetic point of view. It indicates the time of crown closure as the trees become older and also the resistance of the trees to the extrenal environmental influences. The ability of the trees to form narrow or large crowns is considered to be an inherited character with adaptive value (STERN and ROCHE, 1974; ZIMMERMANN and BROWN, 1971). At the age of five years clones varied considerably. Clone 17 had the largest diameter of the crown (215 cm), which was more than double the diameter of clone 23.

Branch Angle

Branch angle is considered to be an economically important character because it is related to wood quality. Trees with narrow or acute branch angles were not selected as parents, because they produce larger knots, which include a greater proportion of undesirable reaction wood (VON WEDEL *et al.*, 1967). Although the clones were selected for crown form, a considerable amount of variation in branch angle among them was detected *(Table 2)*. In the first whorl branch angle varied from 33° (clone 38) to 56° (clone 24); both clones were selected in the same geographic area (Parnon mountain). Within the same clone the branch angle increases as the age of the branch increases. These results are in agreement with EHRENBERG (1963; 1966) and indicate, that the position of individual branches changes considerable with the age of the trees. But which are the forces which make the branches to change their orientation? ZIMMERMANN and BROWN (1971) pointed out that, as the branches extend in length, their weight increases and their angles are regulated by the interacting factors of gravity, light and internal genetic mechanisms. According to the same authors the change of the branch angle with the age, seems to be in harmony with the requirement of the trees for water. In young trees with more acute angles much of the run-off water from precipitation is collected near the main bole where the active

Table 2. — **Clone mean values of 16 characters in a 5-year-old black pine seed orchard at Koumani, Peloponnesos.**

Clone	Height	Length ter. shoot	Lateral buds	Number of branches			Length of branch			Thickness of branch			Branch angle			Crown diamet.
	cm.	cm.	no.	Whorl 1	Whorl 2	Whorl 3	Whorl 1 cm.	Whorl 2 cm.	Whorl 3 cm.	Whorl 1 mm	Whorl 2 mm	Whorl 3 mm	Whorl 1 deg.	Whorl 2 deg.	Whorl 3 deg.	cm.
1	169	48	5.2	5.0	4.2	3.7	36	65	80	14	17	18	40	65	75	133
2	195	49	5.2	5.0	4.9	4.1	39	74	108	14	18	23	43	65	70	187
3	203	56	4.1	3.6	2.9	3.2	46	76	97	16	18	19	47	71	78	167
4	197	52	6.3	6.0	5.7	6.2	44	75	92	14	18	19	41	63	73	173
5	155	48	5.3	4.7	4.5	4.0	40	55	66	16	17	15	37	70	82	126
6	238	66	5.1	4.7	5.0	4.0	48	85	108	16	20	22	39	60	71	176
7	194	56	6.8	5.8	6.1	4.6	45	71	89	15	18	19	47	67	73	139
8	181	53	4.4	3.4	4.4	4.0	43	67	84	15	17	17	48	69	75	145
9	155	51	4.0	3.8	5.3	4.0	40	64	83	14	16	18	37	58	61	113
10	189	45	3.3	3.5	3.4	4.0	37	73	103	15	19	22	43	60	69	152
11	189	58	5.8	5.0	4.3	3.5	40	77	95	13	17	18	44	53	59	133
12	184	51	5.7	5.3	5.2	4.7	42	63	83	15	17	19	42	65	70	130
13	181	50	4.7	4.2	4.5	3.3	34	58	83	13	15	13	43	60	65	130
14	202	53	5.3	5.7	5.3	4.4	37	68	95	14	17	20	52	69	75	156
15	215	54	4.3	5.1	4.2	5.1	46	74	100	15	19	21	37	55	64	175
16	169	49	6.4	4.9	5.7	3.9	37	60	75	14	16	18	45	64	73	126
17	222	52	3.6	3.6	4.0	3.6	41	79	116	13	17	22	45	64	70	215
18	210	52	4.1	4.4	4.0	4.1	41	83	113	15	20	23	42	60	76	193
19	200	50	4.1	4.5	4.1	4.1	39	68	96	16	18	22	50	64	71	155
20	194	56	4.2	5.2	4.1	3.8	45	77	91	14	19	20	49	70	80	179
21	202	49	5.3	5.4	5.0	4.7	39	71	94	14	17	20	38	57	71	164
22	183	49	3.7	4.6	3.6	3.8	42	67	87	13	16	18	37	61	70	143
23	156	53	5.5	4.9	4.5	3.4	35	47	60	13	13	13	48	74	82	92
24	185	53	3.7	4.0	3.2	3.4	45	69	91	14	16	20	56	77	84	155
25	191	62	6.5	5.5	5.1	4.6	45	67	87	14	17	17	42	67	74	151
26	165	63	7.1	5.5	4.8	4.6	45	64	69	13	14	13	48	78	86	123
27	185	60	5.8	4.2	4.2	4.1	48	74	82	15	18	18	53	72	82	127
28	158	46	6.2	5.5	4.7	4.1	39	64	64	14	16	15	45	61	79	108
29	192	64	5.6	4.8	3.8	4.1	48	71	84	14	16	16	50	77	86	144
30	188	53	4.4	4.8	4.6	4.7	43	68	80	16	18	18	52	77	88	150
31	210	60	6.5	5.1	5.9	4.1	51	71	90	16	17	17	42	64	77	161
32	155	42	5.8	5.6	5.1	4.8	36	62	83	12	15	18	41	65	71	137
33	190	57	5.5	4.7	5.1	4.7	43	72	84	14	17	17	34	61	75	142
34	199	62	5.5	4.9	4.8	3.9	42	69	85	14	15	16	50	67	74	142
35	185	60	5.6	5.7	4.3	4.3	45	62	79	13	15	16	44	65	76	134
36	187	59	5.7	5.0	5.3	4.3	40	68	90	13	15	17	56	73	81	152
37	186	59	5.4	4.3	4.4	4.0	46	73	90	13	16	17	42	73	83	163
38	191	56	4.5	5.3	4.1	4.6	46	80	107	14	17	20	33	63	70	171
39	211	63	4.1	4.3	3.7	3.2	50	76	92	15	18	18	42	61	66	140
40	146	45	6.6	5.1	4.0	4.2	36	57	70	13	15	15	50	78	82	114
41	211	67	4.5	3.5	3.8	4.8	44	80	95	14	18	18	45	61	75	159
42	178	52	6.4	5.7	5.3	4.2	45	70	87	14	16	17	37	64	74	150
43	155	55	5.1	4.5	5.2	3.5	39	51	71	14	13	15	50	79	84	121
44	150	51	5.1	4.9	4.7	4.0	41	57	71	14	14	14	47	68	74	108
45	217	74	6.7	5.9	4.6	3.6	54	85	94	14	16	16	41	71	84	153
46	168	50	4.7	4.3	4.5	3.8	42	71	83	14	16	18	46	64	75	129
47	151	55	4.9	5.0	4.6	3.0	35	54	65	12	13	13	47	73	81	108
48	176	55	4.4	4.5	4.4	4.3	45	75	90	13	16	16	53	73	79	150
49	162	54	6.0	5.2	5.8	5.8	43	66	78	13	14	16	47	76	84	123
50	164	54	5.8	6.3	5.8	4.0	39	57	73	15	16	17	49	70	81	121
51	185	60	6.7	6.0	4.6	3.6	37	63	78	13	14	15	51	79	80	122
52	161	59	4.7	3.8	3.7	3.6	44	62	72	13	14	14	39	61	70	109
$\bar{X}$	184	54.8	5.2	4.8	4.6	4.1	37.5	68.4	86.2	14.1	16.4	17.6	44.8	67.0	75.5	144
Low.	146	42	3.3	3.4	2.9	3.0	34	47	60	12	13	13	33	53	59	92
High.	238	74	7.1	6.3	6.1	6.2	54	85	116	16	20	23	56	79	88	215
S.D.	20.9	6.21	0.94	0.71	0.71	0.61	12.83	8.47	12.45	1.04	1.72	2.51	5.62	6.62	6.57	24.5

root system is extended, whereas in older trees with greater branch angle the water is channeled outwards.

Correlation among Characters

The phenotypic correlation coefficients on individual tree basis among all combinations of the characters are shown in *Table 3*. The most important relationships are discussed below.

Total tree height was correlated with the length of terminal shoot (r = 0.53) but the relationship found is weaker than that (r = 0.83) reported by Ehrenberg (1963) between the same characters. As expected, total tree height was also strongly correlated with the length and thickness of the branches. The correlations between total tree height and length of branches increase with the whorl number. Similar trends of increasing values with the age of the branch were also reported by Ehrenberg (1963) in Scots pine.

The relationship between total tree height and crown diameter was found to be very strong (r = 0.76). The r-values between tree height and branch thickness were lower than those between height and branch length. Total tree height was positively correlated with the number of branches and slightly negatively related to the branch angles.

The number of lateral buds was, as expected, positively correlated with the number of branches per whorl. But the r values found were quite small, indicating that not all lateral buds develop into branches; some of them are aborted during their development. Small phenotypic correlations were also found between the number of branches in the different whorls, indicating that some of the branches of each whorl are aborted, do not develop well, or remain weak and are not measurable. Finally the correlation between branch length and branch thickness increases with the age of the whorl.

Variance Components and Repeatability Estimates

The between clone and the between ramets within clones variance components, the repeatability values on individual tree basis (R_1) together with their standard errors and the repeatabilities on the clone mean basis (R_2) are

Table 3. — Matrix of phenotypic correlations on individual tree basis of 16 characters[1]).

Characteristics	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Tree height	.53	-.03	.03	.06	.15	.52	.71	.75	.41	.60	.59	-.09	-.21	-.19	.76
2. Length of terminal shoot		.23	.12	.08	.09	.66	.38	.25	.33	.16	.05	.03	.06	.05	.21
3. Number of lateral buds			.22	.24	.11	.11	-.02	-.12	.06	-.08	-.13	-.04	.07	.09	-.12
4. No of branches in whorl 1				.33	.22	.08	-.01	-.03	-.03	-.04	-.07	.03	.12	.08	-.01
5. No of branches in whorl 2					.27	.03	.01	.00	.03	-.01	.01	.00	.05	.04	.05
6. No of branches in whorl 3						.14	.13	.11	.10	.11	.10	-.04	-.05	.00	.17
7. Length of branch in whorl 1							.52	.36	.62	.38	.22	-.14	.01	.01	.33
8. Length of branch in whorl 2								.69	.37	.78	.56	-.12	-.31	-.18	.64
9. Length of branch in whorl 3									.30	.62	.79	-.13	-.28	-.36	.82
10.Thickness of branch in whorl 1										.50	.34	-.12	-.01	-.01	.28
11.Thickness of branch in whorl 2											.65	-.11	-.35	-.21	.57
12.Thickness of branch in whorl 3												-.11	-.29	-.34	.66
13.Branch angle in whorl 1													.31	.25	-.10
14.Branch angle in whorl 2														.57	-.19
15.Branch angle in whorl 3															-.17
16.Crown diameter															

[1]) Degrees of freedom for all combinations 1031. Values greater than.06 and .08 are statistically significant at the .05 and .01 Probability level respectively.

presented in *Table 4*.

The repeatability value (R_1) for total tree height was 0.40 and that for length of terminal shoot 0.30. The repeatability estimates of the length and thickness of the branches increase with the age. The values for branch length were always higher than those for branch thickness. An increase of the R_1 values with the age of the trees was also found in the branch angle. Crown diameter, a complex character, which reflects branch length and branch angle, had the higher R_1 value (0.42). As expected, the repeatability values based on clone means (R_2) were higher, ranging from 0.80 for branch thickness of the first whorl to 0.93 for crown diameter and total tree height. High repeatability values based on provenance means in black pine were reported by WILCOX and MILLER (1975). They estimated values ranging from 0.76 for forking up to 0.94 for tree height.

An examination of S.E. (R_1) reveals that repeatability values were estimated with adequate accuracy. This is due to the nature of the material used (clones) and the large number of ramets (a mean of 19.86 per clone).

Improvement of black pine by cloning at present is rather impractical. If however vegetative propagation techniques can be developed in the future, then a considerable gain can be expected in any character by selecting clones and vegetative propagation. Also the high repeatability values of crown diameter, tree height and branch angle combined with the weak negative relation-

Table 4. — Variance components and repeatability estimates[1]).

Characteristic	Var. components σ^2_W	σ^2_C	Repeat. estimates R_1	R_2	S.E.(R_1)
Total tree height	622.19	412.920	0.40	0.93	0.080
Length of terminal shoot	80.79	34.520	0.30	0.89	0.064
Number of lateral buds	2.59	0.797	0.23	0.86	0.053
No of branches in whorl 1	1.24	0.421	0.25	0.87	0.056
No of branches in whorl 2	1.26	0.441	0.26	0.87	0.058
No of branches in whorl 3	0.96	0.332	0.26	0.87	0.058
Length of branch in whorl 1	59.31	16.587	0.22	0.85	0.051
Length of branch in whorl 2	132.55	65.329	0.33	0.91	0.069
Length of branch in whorl 3	243.57	148.173	0.38	0.92	0.077
Thickness of branch in whorl 1	4.04	0.815	0.17	0.80	0.042
Thickness of branch in whorl 2	6.60	2.576	0.28	0.88	0.061
Thickness of branch in whorl 3	11.79	5.773	0.33	0.91	0.069
Branch angle in whorl 1	80.84	25.702	0.24	0.86	0.054
Branch angle in whorl 2	87.64	39.024	0.31	0.90	0.066
Branch angle in whorl 3	66.16	40.000	0.38	0.92	0.077
Crown diameter	788.58	564.982	0.42	0.93	0.082

[1]) Degrees of freedom for all characters: Between clones 51, within 981. The between clone differences are statistically significant for all characters at the 0.01 probability level.

ship between crown diameter and branch angle promise that these characters can be combined in a breeding program to develop narrow crowned strains of black pine with a wide branch angle.

Conclusions

From the study of 16 growth and branching characters in a 5-years-old clonal seed orchard of black pine comprising 52 clones the conclusions are:

- There are significant differences among clones in all character studied.
- Branch angle is not a stable character and increases with the age of the whorl, while the number of branches per whorl decreases.
- Repeatability values for branch length and branch thickness increase with the age of the whorl and are always higher for branch length.
- Growth and branching characters are genetically less controlled than the morphological and anatomical features of the needles reported in a previous study in the same population.
- Branch angle and crown diameter are loosely negatively correlated characters indicating that they can be combined in a breeding program to develop a narrow crowned strain of black pine with wide angle branches.

Acknowledgements

The author is thankful to Mr. N. Pislis for his help in the collection of the data.Thanks are also extended to Dr. J. Papadopoulos and Mr. N. Cooling for reading the draft.

Literature

Bassiotis, C. Variation in characteristics of black pine in Greece. Scientific Annals of Agriculture and Forestry Faculty, Thessaloniki 11: 79—133 (1967). —— Becker, A. W.: Manual of Procedures in Quantitative Genetics. Washington State Univ. Press, Pullman, 170 pp. (1967). —— Ehrenberg, C.: Genetic variation in progeny tests of Scots pine (*Pinus sylvestris* L.). Studia Forestalia Suecica, No. 10 (1963). —— Ehrenberg, C.: Parent progeny relationship in Scots pine (*Pinus sylvestris*). Studia Forestalia Suecica, No. 40 (1966). —— Falconer, D. S.: Introduction to Quantitative Genetics. The Ronald Press Company, New York (1960). —— Hattemer, H. H., Anderson, E. ad Tamm, C. O.: Effects of spacing and fertilization of four grafted clones of Scots pine. Studia Forestalia Suecica, No. 141 (1977). —— Matziris, D.: Seed problems in Greece and their solution. Forest Research Institute reports **VI** (1): 29—49 (1978a). —— Matziris, D.: Clonal seed orchard of black pine in Peloponnesos/Greece, for the production of genetically improved seed. To Dassos (80—81): 34—45 (1978b). —— Matziris, D.: Grafting work of black pine made for the production of the materials used in the establishment of the seed orchard Koumani Ilians. Forest Research Institute, Forest Research **111** (3): 259—273 (1982). —— Matziris, D.: Genetic variation in morphological and anatomical needle characteristics in the Black pine of Peloponnesos. Silvae Gen. **33** (4—5): 164—169 (1984). —— Mavrommatis, G.: The bioclimate of Greece. Relation of climate and natural vegetation. Bioclimatic maps. Forest Research Institute, Forest Research 1 (1980). —— Nakos, G.: Forest soils of Greece. Physical, chemical and biological properties. Forest Ecol. Managem. **2**: 35—51 (1979). —— Palmberg, C.: Species introduction and tree improvement FO: DP/GRE/78/003. Working Document No. 1, Athens (1983). —— Shelbourne, C. J. A.: Tree breeding methods. Forest Research Institute, New Zealand Forest Service, Rotorua. Technical paper No. 55 (1969). —— Snedecor, G. and Cochran, W.: Statistical Methods. The Iowa Univ. Press, Ames (1967). —— Stern, K. and Roche, L.: Genetics of Forest Ecosystems. Springer-Verlag, Berlin, Heidelberg, New York (1974). —— Swiger, L. A., Harvey, W. R., Everson, D. O. and Gregory, K. E.: The variance of intraclass correlation involving groups with one observation. Biom. **20**: 818—826 (1964). Wedel, K. W. von, Zobel, B. J. and Shelbourne, C. J. A.: Prevalence and effects on knots in young loblolly pine. For. Prod. Jour. **18** (9): 07—103 (1967). —— Wilcox, M. D.: Wood brightness in loblolly pine. Ph. D. Thesis, School of Forest Resources, N. C. State Univ., Raleigh, 142 pp. (1974). —— Wilcox, M. D. and Miller, J. T.: Pinus nigra provenance variation and selection in New Zealand. Silvae Gen. **24** (5—6): 132—140 (1975). —— Zimmermann, M. and Brown, C.: Trees, Structure and Function. Springer-Verlag, New York, Heidelberg, Berlin (1971).

Geographic Variation in Pinus armandii Franch.

By Ma Chang-Geng

Chinese Academy of Forestry, Wan Shou Shan,
Beijing 100091, P. R. China

(Received 28th September 1987)

Abstract

The natural range of *Pinus armandii* Franch. covers a large area from about 23°30' N to 36°30' N and 88°50' E to 113°00' E, whithin which the ecological gradient is considerable. The genetic differentiations of the species are obvious. Although most of the characteristics of *P. armandii* varied clinally with latitude, our research revealed that all provenances may be divided into two geographic groups that are obviously different from each other in growth vigour, cold resistance as well as in many morphological characters. The provenances from Yun-Guei Plateau (come from the Yunnan, Gueizhou Provinces and southwestern part of Sichuan Province, namely southern provenances), though fastgrowing, but all died from winter frost and desication when planted in northern portion of range. The more northern were the provenances introduced in the south of range the worse they grew. Gradually they lost production value all of them.

Key words: Pinus armandii Franch., provenance trial, height growth, hardiness, geographic variation, clinal pattern.

Introduction

A provenance test of a tree species, is to reveal the pattern of geographic variation of the main features of the species so as to provide the necessary scientific basis for reasonable transfer of seeds and for the strategy of genetic improvement. Thus many countries around the world have started provenance trials of their main reforestation tree species (Wright, 1976).

Pinus armandii Franch. is one of the important reforestation tree species in sub-alpine regions in our country. The species is seldom found below 1000 m elevation and most common at elevations from 1300 m to 2300 m (Zheng, 1978).