Variation of wood density in radiata pine grown from four seed sources at two sites in Greece

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Summary

A study based upon two 10-year-old, experimental plantings of four seed sources of radiata pine *(Pinus radiata* D. DON) growing in two locations in Greece was undertaken to provide information related to wood density variation. The trees of the four seed sources were grown in a randomized complete block design with ten tree plots in each of the four replications. The whole experiment was replicated in two locations; Borsi, located in the northwestern part of the Peloponnese peninsula, and near Procopi village, in the north part of Evia island.

At the age of ten years (fall 1977), every second tree in each row was removed and cross sectional disks were taken at breast height for wood density determination. Analysis of the data showed that:

1. There is a large variability in wood density among trees of radiata pine growing under the same environmental conditions.
2. The seed source had no significant effect on the wood density produced and it was speculated that this may have resulted from the nature of the materials used in the study (cultivated seed sources and not native origins were used).
3. The site where trees were grown, strongly influences the wood density produced. Trees growing in the southern warmer climate produce wood of higher density.
4. No evidence was found for any seed source X location interaction of significant importance.
5. Wood density of radiata pine appears to show a weak negative relationship with DBH and is unrelated to height.
6. Selection of individual trees for irnproving wood density is promising, while selection in the level of seed source is not expected to result in any Progress.

Key words: Provenance, seed source, variation, components of variance, *Pinus* radiata, wood density.

Zusammenfassung

Bei zehnjährigen *Pinus radiata* D. DON — Nachkommenschaften in einem randomisierten Anbauversuch auf zwei Standorten in Griechenland, die aus vier Sekundär-Herkünften in Australien, Neuseeland und Spanien stammen, wurde die Holzdichte untersucht. Hierbei wurde festgestellt, daß sich die Herkünfte in der Holzdichte nicht signifikant unterscheiden, wobei die Ursache darin gesehen wird, daß im Versuch keine Originalherkünfte aus dem natürlichen Verbreitungsgebiet der Baumart verwendet wurden. Dagegen ergab sich ein starker Einfluß der Standortbedingungen, wobei die Holzdichte im wärmeren Klima größer war.

Introduction

Radiata pine *(Pinus radiata* D. DON) is a fast growing species with wide reputation. From its restricted natural range, in California, it has been introduced in many countries with great success and is presently used in large scale reforestation projects in New Zealand, Australia, Latin America, South Africa, Spain and other countries (SCOTT, 1960; ROCKEL, 1974). In Greece, although the first introduction of *Pinus radiata* dates back to 1913 when it was planted with success in the arboretum of Vetina (MICHOPULOS, 1931) in the southern part of Greece, experiment plantings of different seed sources, replicated over environments, have only recently been established (COOLING, 1971).

It is well known that the density of wood is a major factor determining the yield and quality of both fiber and solid wood praduct (ZOBEL *et al.*, 1972; BUIJTENEN, 1969, MC MILLIN, 1968; ELLIOT, 1970). BAREFOOT *et al.* (1970) concluded that wood density is the most important single property which can be used to predict timber strengh and paper properties. Therfore it is valuable for tree breeders to know the variation that can be found among trees and populations and how it is influenced by the environment in order to be able to make judgements concerning possibilities of improvement through the mechanisms of selection and breeding.

The purpose of this paper is to study tree to tree variation and seed source variation in wood density of 10-year-old *Pinus radiata* planted *in* two locations in Greece and to determine the magnitude of interelationships that may exist among density and growth characteristics.

Materials and Methods

Plant materials

The plant materials used in this study were obtained from 10-year-old radiata pine seed source tests growing in two localities in Greece. The four seed sources from which the experimental plantings were established are as follows:

1. Stromolo. Plantation A.C.T., Australia
2. Talaganda. Seed orchard, N.S.W., Australia
3. Bilbao. Viscaya, Spain
4. Kaingaroa. Plantation, New Zealand.

Experimental Design and Establishment

One-year-old open rooted seedlings of the four sources produced at Lapa nursery, were transplanted in February 1969 in five locations throughout Greece, two of which were thinned and provided the data used in this study. The experiment was planted in randomized complete block design with four replications per location. The experimental unit (plot) comprised ten seedlings arranged in two rows within the plat, at 1.5 X 1.5 meters spacing.

Description of *the Planting Sites*

The locations of the two plantings belong to two different geographic regions with different climatic and edaphic conditions. The first is located at Borsi in the northwestern part of the Peloponnese peninsula and the other close to Procopi village in the north part of the Evia island. Some climatic data of the two locations are given in ***Table*** 1. The Borsi site was covered before planting by a dense growth of *Erica verticilata*. The Evia site was abandoned agricultural land used for many years for grazing. The soil of the first location is a red yellow podsol, while that of the second is a red brown loam. Both sites were well prepared before planting.

Field Sampling

In the fall of 1977 at the age of ten years every second tree in the row was removed. Five trees per plot of each of the four sources were cut. This gave rise to a total number of 80 trees per location. Following cutting, a 5 cm thick disc was removed from each tree at breast height. The bark of the discs was removed and samples were transferred to

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Table 1. — Climatic data (1968—1975) of the two locations, where the experimental plantings of *Pinus radiata* are growing.

Characteristic	Location Borsi	Evia
Latitude	37° 57'	38° 45'
Longitude	21 26'	23° 29'
Elevation	160 m	100 m
Mean annual temperature	17.0 °C	15.6 °C
Mean temperature of the warmer months (June-September)	24.3 °C	22.4 °C
Mean minimume temperature of the cold season (December-March)	6.2 °C	2.8 °C
Absolute minimum temperature	-4.0 °C	-5.5 °C
Annual rainfall	870.0 mm	707.6 mm
Summer rainfall (June-September)	54.0 mm	61.6 mm

the laboratory for analysis. All discs were taken so as to avoid nodal swelling, visible compression wood associated with branch clusters, or any other marked stem deformation near the specified point. In the laboratory, wood density of the whole disc was estimated by usual methods (MATZIRIS, 1971), and the resulting values were subjected to statistical analysis.

Statistical Analysis

The analysis was based on disc values of wood density estimated at breast height. Separate evaluation for each location was carried out applying an appropriate form, for a randomized complete block design with more than one (5) observation per experimental unit (plot), given by STEEL and TORRIE (1960, page 146, section 8.7). Following, an overall analysis for both locations combined, was performed according to the procedures described by SNEDECOR and COCHRAN (1967, page 375, section 12.13). SATTERTHWAITE and COCHRAN's approximate F-test was used to determine the effect of location (ANDERSEN, 1960; SNEDECOR and COCHRAN, 1967, page 369, section 12.11).

Results

The mean values for total tree height, DBH and wood density per seed source and location are given in *Table 2.* In the Borsi planting the mean wood density among seed sources varies from 0.372 g/cm³ (Stromolo) to 0.375 g/cm³ (Bilbao), while in the location of Evia mean values from 0.351 (Talaganda) to 0.362 (Kaingaroa and Bilbao) were found. The analysis of variance *(Table 3)* reveals no significant differences among the seed sources tested. A large amount of tree to tree variation was observed within the seed sources and locations. Correlation coefficients on an individual tree basis between wood density and diameter and wood density and height were found to be quite small *(Table 4).* Regression analysis of the wood density on total

Table 3. — Analysis of variance for 10-year-old wood density of four *Pinus radiata* seed sources grown at two locations (Borsi and Evia) in Greece. Analyses by location and locations combined.

Source of variation	D.F.	M. squares[1]	Estimated components of variance	% of component contribution to total variance
		A. B O R S I		
Replications	3	2.83667**	σ^2_r=0.6315	15.8
Sources	3	0.01666	σ^2_s=0.0	0.0
Replications x Sources	9	0.47444	σ^2_{rs}=0.0	0.0
Within plot	64	0.63148	σ^2_w=0.1181	84.2
		B. E V I A		
Replications	3	0.28433	σ^2_r= 0.0	0.0
Sources	3	0.59800	σ^2_s= 0.01188	3.6
Replications x Sources	9	0.36033	σ_{rs}=0.01189	3.7
Within plot	64	0.30087	σ^2_w= 0.30087	92.7
		C. C O M B I N E D		
Locations	1	9.8800*		
Replications/Location	6	1.5605		
Sources	3	0.3427		
Sources x Locations	3	0.2763		
Sources x Repl./Location	18	0.4174		
Within plot	128	0.4662		

1/ All mean squares x 1000

Table 4. — Correlation coefficient (r) on an individual tree basis, between wood density and total tree height and wood density and DBH in 10-year-old experimental plantings of *Pinus radiata*, grown in two locations in Greece.

Combination	Location[1] Evia	Borsi	Overall
Density x total tree height	0.11	-0.17	-0.09
Density x DBH	-0.11	-0.35**	-0.30**
Degrees of freedom	78	78	154

1/** Statistically significant at the 0.01 probability level

Table 5. — Regression analysis of wood density on total tree height and wood density on DBH, in 10-year-old experimental plantings of *Pinus radiata*, grown in two locations in Greece.

Source of Variation	D.F.	Mean Squares[1] Evia Height	Evia DBH	Borsi Height	Borsi DBH
Regression	1	0.0003	0.0003	0.0012	0.0052**
Deviation	78	0.0003	0.0003	0.0005	0.0004

[1]) ** Statistically significant at the 0.01 probability level.

Table 2. — Mean ($\bar{X}$) and standard error (S.E.) of total tree height, DBH and wood density in 10-year-old experimental plantings of *Pinus radiata* growing in two locations in Greece (Borsi and Evia).

Seed source	Borsi[1]) Height (m) $\bar{X}$	S.E.	DBH (cm) $\bar{X}$	S.E.	Density (g/cm³) $\bar{X}$	S.E.	Evia[1]) Height (m) $\bar{X}$	S.E.	DBH (cm) $\bar{X}$	S.E.	Density (g/cm³) $\bar{X}$	S.E.
Stromolo Australia	10.27	0.246	10.19	0.466	0.372	0.006	9.87	0.236	9.55	0.293	0.355	0.003
Talaganda Austral.	10.10	0.301	9.85	0.505	0.374	0.005	9.81	0.199	9.90	0.274	0.352	0.004
Bilbao Spain	9.38	0.417	9.36	0.842	0.375	0.006	9.99	0.187	10.23	0.339	0.362	0.004
Kaingaroa N.Z.	9.70	0.296	8.76	0.477	0.373	0.006	9.84	0.326	9.63	0.358	0.362	0.004
Overall mean	9.86	0.164	9.54	0.309	0.373	0.005	9.88	0.119	9.83	0.158	0.358	0.004

[1]) Number of trees per seed source and location = 20. Number of trees per location = 80.

tree height and wood density on DBH resulted, in only one case out of the four, in a significant b value *(Table 5)*.

Discussion

The mean wood densities of the seed sources found in this study *(Table 2)* are a little higher than those reported by BURDON and BANNISTER (1973) in a 5-year-old provenance study of this species grown in New Zealand; they estimated, using the same method, wood densities of 0.371 g/cm³ for Guatalupe population, 0.334 g/cm³ for Cambria and 0.341 and 0.337 g/cm³ for the local sources Kaingaroa and Nelson respectively.

The lack of significant differences among the seed sources (Table 3) may be related to the provenance of the seed sources used, because the original provenance of the seed sources is not known. Since radiata pine is growing as an exotic in the countries from where the seed was introduced to Greece, the possibility exists that all the seed sources used may have an initial common origin. If that is true, then it can be accepted that the length of time of radiata pine has grown in its new homes was insufficient to result in selection for different wood densities. The effect of location on wood density was found significant at the 0.05 probability level. Borsi materials resulted in an overall mean density of 0.373 g/cm³, while that from Evia 0.358 g/cm³. This effect was consistent for all seed sources and no seed source by location interaction of significant importance was evident.

The effect of environment on the wood density of forest tree species has been extensively studied and the published results are often confusing and contradictory (LEDIG *et al.*, 1975). In relation to radiata pine, HARRIS (1966) found that the latitude where the trees are grown has a strong influence on the wood density produced. It has been also reported by COWN (1974) that the density decreases with increasing latitude at a rate of 10 kg/m³ per each degree. Mean annual temperature was also found to affect wood density of young radiata pine (HARRIS, 1966; BURDON and HARRIS, 1973). Although in the present study the northern planting of Evia had lower wood density from the southern Borsi, geographic effect is confounded with site effect and no conclusion about any pattern can be drawn.

The correlation analysis showed that a weak relationship exists between wood density and growth rate of the trees *(Table 4)*. For the Borsi materials the correlation on an indivdual tree basis were: $r = -0.17$ between density and total tree height and $r = -0.35^{**}$ between density and DBH. Although the later correlation is highly significant, the DBH alone accounts for only 12.2 percent of the variation in wood density of individual trees, making this relationship practically meaningless. In general, the correlations found indicate that there is a negative but very weak relationship between wood density and growth rate in radiata pine. This relationship is greater for DBH and lower, nearly non-existent, for total tree height. BURDON and HARRIS (1973) have also reported negative but weak relationship between wood density and growth rate in radiata pine growing in different localities in New Zealand.

The components of variance and their proportionate contribution to the total variation are shown in *Table 3*. In the Borsi location the source and replication × source (experimental error) effects were non-existent. The replication accounted for 15.8 percent of the total variation, and the within-plot contribution was 84.8 percent. In the second location (Evia), due to the uniformity of the site, no replication effect was evident. The source and replication × source effects accounted for 3.6 and 3.7 percent respectively, while the within-plot effect was the main source of variation, accounting for 92.7 percent of the total. This indicates that tree to tree variation is impressively large (in Borsi from 0.328 to 0.420 g/cm³ and in Evia from 0.323 to 0.410 g/cm³), and gives hope for considerable improvement through the application of selection principles. On the other hand, selection of seed sources is not expected to result in progress, since no variation for this characteristic among the seed sources was found.

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