Provenance and Family Variation in Height and Diameter Growth of *Cupressus lusitanica* MILL. at 28 Months in Costa Rica

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(Received 15th August 1995)

Summary

Results of a provenance / progeny trial of *Cupressus lusitanica* in Costa Rica are described. At age 28 months, progeny of plus-trees selected primarily for stem straightness and cylindricity had grown significantly faster than three commercial controls and a seedlot produced from a Colombian clonal seed orchard. The estimated values of additive genetic coefficients of variation (10.2% to 15.9%) and heritabilities (0.12 to 0.21) were within the ranges typically found in forest trees. There was no evidence for important differences between the Costa Rican, derived provenances.

Key words: additive genetic variation, heritability, progeny testing, provenance variation.

FDC: 232.11; 232.12; 165.5; 174.7 *Cupressus lusitanica;* (728.6).

Introduction

Cupressus lusitanica, a native of Mexico, El Salvador, Guatemala and Honduras (STYLES and HUGHES, 1983), was first introduced to Costa Rica at least 100 years ago (HOLDRIDGE, 1953). The species produces durable, easily-worked and attractive timber (LAMPRECHT, 1990) and has become one of the timber trees most planted by smallholder farmers in the highlands of Costa Rica, both in block plantations and in windbreaks (CHAVES and FONSECA, 1990). There is some evidence to suggest that the base population is of at least acceptable genetic quality: in a Costa Rican provenance trial reported by SOARES (1973), 2 local derived provenances grew faster than 7 other sources from Mexico, Kenya and New Zealand, whilst in a Colombian provenance trial reported by VELEZ (1984), the progeny of 3 trees selected in Costa Rica were taller than the other 16 seedlots (families from Kenya and Colombia, commercial bulked lots from Italy, Mexico and Portugal). Nevertheless, the amount of phenotypic variation between individual trees suggests that there is room for genetic improvement in traits of commercial interest, as has proved to be the case in Colombian (LADRACH, 1979; LADRACH and GUTIERREZ, 1979) and East African (DYSON and RAUNIO, 1977) populations of the species. For this reason, in 1989, CATIE, a regional organization dedicated to the improvement of smallholder forestry and agroforestry systems, initiated a programme of genetic improvement of the species.

The present document describes the results at 28 months of a provenance/progeny test located in the Cordillera Central of Costa Rica. The principal objectives of the test are to provide a base for recommendations of appropriate seed sources for reforestation in the breeding zone in question and, after conversion to a seedling seed orchard, to produce improved seed.

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Materials and Methods

Treatments

The treatments consist of 45 open-pollinated families of 8 Costa Rican derived provenances: Cipresal, Birrí, Heredia (11 plus-tree progenies and 1 progeny from an 'average tree'); Monte de la Cruz, Heredia (7 plus-tree progenies and 1 progeny from an 'average tree'); Finca La Lucha, León Castro Cortés, San José (10 plus-tree progenies and 1 progeny from an 'average tree'); Bosque de la Hoja, Heredia (8 plus-tree progenies); Fraijanes, Poas, Alajuela (2 plus-tree families); El Roble, Heredia (1 plus-tree family); Paso Llano, Heredia (2 plus-tree families); Calle Lobos, Los Angeles, Heredia (1 plus-tree family). The mother trees of the plus-tree families were selected as having straight and cylindrical stems and a diameter at breast height (dbh) at least equal to that of the stand mean. In addition to the family seedlots, 4 bulk lots were included: 1 from a Colombian clonal seed orchard (La Arcadia, Popayán) belonging to Smurfit Carton of Colombia, and 3 local commercial controls supplied by the Latin American Forest Tree Seed Bank, CATIE, Costa Rica (Santa María de Dota; Las Chorreras, San Rafael de Heredia; Prusia, Cartago). All 3 commercial controls represent additional Costa Rican derived provenances, and are composed of the bulked seed of 8 to 20 healthy trees of at least average size and acceptable stem form, selected in commercial plantations.

Experimental site and planting details

The experiment was planted in May 1992 at a high elevation site located in Santa Cruz de Turrialba, Costa Rica (latitude latitude 9°58' north, longitude 83°47' west, elevation 2100 m a.s.l., mean annual precipitation 2912 mm, mean annual temperature 13.9 °C, mean of 1.5 dry months (< 80 mm) per year). Before planting, the site was under pasture, with a few trees remaining of the original forest cover.

The progeny of the 3 unselected trees and the Colombian material were nursery sown 41 and 78 days respectively after the rest of the material, which was in the nursery for a total of 178 days.

Experimental design, measurements and statistical analysis

A randomized complete block design was used. The families and the 4 bulk lots were planted in 3-tree line plots, with 24 blocks. Two or more surround rows, composed of a mixture of the families, were planted around the entire experiment. Total tree height and diameter at 1.3 m (dbh) were measured at 28 months from outplanting, except in the case of the unselected families and the Colombian seedlot which, in order to reflect their later nursery sowing date (see above), were measured at 28 months plus 41 days and 78 days respectively. Trees of less than 1.3 m height were booked as having zero dbh. Survival percentages were derived from the data.

The experiment was designed to test the following null hypotheses (Ho) for the traits in question: Ho1 (there are no differences in the parametric mean values of the different provenances); Ho2 (there is no difference between the para-

Table 1. – Linear models used in the analysis of variance of a progeny trial of *Cupressus lusitanica* in Santa Cruz de Turrialba, Costa Rica.

Hypotheses[1]	Model[2]	Random effects in model	Error term (F-test denominator)
1, 2, 3, 4	$Y_{ikl}=\mu + \phi_i + \beta_k + \varepsilon_{ikl}$	β_{ik}	ε_{ikl}
5	$Y_{jk}=\mu + \alpha_j + \beta_k + \varepsilon_{jk}$	β_k	ε_{jk}
6	$Y_{jkl}=\mu + \alpha_j + \beta_k + \alpha\beta_{jk} + \varepsilon_{jkl}$	all	$\alpha\beta_{jk}$

[1]) see text

[2]) Y_{ikl}=the observed mean value of the response variable 'Y' on the lth tree of the ith provenance in the kth block; μ=the population mean; ϕ_i=the effect of the ith provenance; β_k=the effect of the jth block; ε_{ikl}=the residual variation of the lth tree of the ith provenance in the kth block; Y_{jk}=the observed mean value of the response variable 'Y' on the jth family in the kth block; α_j=the effect of the jth family; ε_{jk}=the residual variation of the jth family in the kth block; Y_{jkl}=the value of the response variable 'Y' on the lth tree of the jth family in the kth block; $\alpha\beta_{jk}$=the interaction of the jth family and the kth block; ε_{jkl}=the residual variation of the lth tree of the jth family in the kth block.

Table 2. – Formulae for genetic parameter estimates in a progeny trial of *Cupressus lusitanica* in Santa Cruz de Turrialba, Costa Rica.

parameter estimated[1]	formula for estimator	notes
additive genetic variance (σ^2_A)	$4\sigma^2_F$	σ^2_F = variance component for half-sib families;
additive genetic coefficient of variation % (AGCV)	$100[\sigma_A / \bar{x}]$,	$\bar{x}$ = experimental mean
h^2 (narrow-sense individual-tree heritability)	$\sigma^2_A / [\sigma^2_E + \sigma^2_{FB} + \sigma^2_F]$	σ^2_E=error variance; σ^2_{FB} =block-family interaction variance

metric mean of the Heredia provenances as a group and that of La Lucha); Ho3 (there is no difference between the parametric mean of the 'selected' provenances as a group and that of the commercial controls taken as a group; Ho4 (there is no difference between the parametric mean of the Costa Rican provenances as a group and that of the Colombian lot; Ho5 (there are no differences between the parametric means of the 49 treatments; Ho6 (there is no additive genetic variation in the Costa Rican base population).

Provenance analysis

Analysis of variance was carried out on height and diameter (see *Table 1* for linear model). Null hypothesis 1 was tested using an 'F' test with the provenance mean square as numerator and the error mean square as denominator. Null hypotheses 2, 3 and 4 were tested using single degree of freedom 'F' tests with the SAS© 'Contrast' statement, as described by STONECYPHER (1989). For provenance analysis purposes, the families of each provenance are considered to constitute non-contiguous provenance plots.

COTTERILL (1990) considers that a minimum of 5 families are necessary for a representative sample of provenances. For this reason, those provenances represented by less than 5 families (Fraijanes, El Roble, Paso Llano, Calle Lobos) were excluded from the provenance analysis. The progeny of the 'average trees' were also omitted.

Family analysis

Mixed model analysis of variance of height and diameter was carried out. No provenance effect was included in the model (*Table 1*) because this is considered to be irrelevant to the main application of the mixed model analysis, i.e. to identify which are the best treatments, independently of whether their superiority is due to provenance or family-within-provenance effects. Null hypothesis 5 was tested using an 'F'-test with family mean square as the numerator and the error as the denominator. Null hypothesis 6 was tested with using a random model analysis of variance. Individual-tree genetic parameters were estimated from the using the formulae detailed in *table 2*.

Results

General

The mean plantation height and dbh at 28 months were 2.70 m and 2.1 cm respectively. The overall survival was 92.3%.

Provenance results

Least squared means for height and diameter are included in *table 3*. Provenance mean height ranged from 2.20 m (Colombian seed orchard, Santa María de Dota control) to 2.80 m (Cipresal, Heredia). Provenance mean dbh ranged from

1.3 cm (Colombian seed orchard) to 2.2 cm (Monte de la Cruz, Heredia). The analysis of variance (*Table 3*) revealed highly significant differences in height growth and diameter amongst the 7 provenances included. The results of the planned comparisons (*Table 3*) indicated that the group of 'selected' provenances (grand mean height 2.73 m, grand mean dbh 2.1 cm) was highly significantly superior to the commercial controls (grand mean height 2.49 m, grand mean dbh 1.8 cm) and to the Colombian seed orchard material. The grand mean height of the Heredia selected provenances (2.75 m) was significantly superior to that of the La Lucha provenance (2.7 m), but the difference is of little practical importance. The 2 groups did not differ significantly in dbh.

Provenance least squared mean survival percentages ranged from 81.9% (Colombian seed orchard) to 95.8% (Prusia commercial control). Due to the generally acceptable survival, no further analysis of this trait was made.

Family results

Family least squares height and dbh means (*Table 3*) varied from 2.2 m and 1.5 cm (family 7) to 3.1 m and 2.6 cm (family 30). The grand least square height and diameter means of the best 10 families (2.90 m, 2.4 cm) was 7.4% and 14.3% respectively above the grand mean and 16.5% and 33.3% respectively above the mean of the 3 commercial controls. The analysis of variance revealed highly significant differences between treatments (*Table 3*). Only 7 families had survival percentages below 90%.

Genetic parameter estimates are included in *table 3*. Height had higher heritability than dbh but lower AGCV. There was highly significant additive genetic variance for both height and diameter (*Table 3*).

Discussion

At 28 months after planting, there is strong evidence for important differences in provenance and family parametric means. Although there appears to be little difference between the three provenances from the north of Heredia and the La Lucha provenance, as a group they clearly have superior juvenile height growth to the 3 commercial controls, particularly with respect to the Santa María Dota source. The reasons for this superiority are not clear and cannot be elucidated from the data presented here. Possibly the superior height growth results from direct or indirect responses to selection for form and diameter. Alternatively or additionally, there may be genetic differences unrelated to the selection applied.

The Colombian seedlot is clearly inferior in the trial. This treatment was measured at the same total age as the other treatments. Nevertheless, it is possible that its inferior growth over the 28 month period might result from its smaller size at planting. Alternatively, it may be that, due to genotype-environment interaction, the genetic superiority (i.e. in Colombia) of the Colombian seed orchard seed is not maintained in the zone of the trial, or that the Colombian base population is inferior to the Costa Rican base population, as suggested by

Table 3. – Proportionally ranked provenance and family least squared means, results of significance tests, and genetic parameter estimates for height and diameter at 28 months in a progeny test of *Cupressus lusitanica* in Santa Cruz de Turrialba, Costa Rica.

CHARACTERISTIC			
dbh (cm)[1]		**height (m)[1]**	
best family (#30) (2.6)		best family (#30) (3.1)	
best 10 families (2.4)		best 10 families (2.9)	
		Cipresal (2.8)	
Monte de la Cruz (2.2)		overall mean, M.C[2]. (2.7)	B.H.[3], La Lucha
Cipresal (2.1)	overall mean	control Chorreras (2.6)	
Bosque de la Hoja (2.0)	La Lucha	control Prusia (2.5)	
control Chorreras (1.9)	Prusia control		
		control Santa María Dota (2.3)	
		Colombian seed orchard (2.2)	worst family (#7)
worst family (#7) (1.5)	control Sta. Ma. Dota		
Colombian seed orchard (1.3)			
'F' values, significance[4]			
global (provenances): F=11.42, p=.0001		F=8.35, p=.0001	
global (all treatments): F=3.3 p=.0001		F=5.2 p=.0001	
global (families): F=3.03, p=.01		F=2.47, p=.01	
controls v. families, F=15.1 p=.0001		F=28.8 p=.0001	
families v. seed orchard F=31.9 p=.0001		F=32.0 p=.0001	
genetic parameters			
heritability[5]	AGCV[6]	heritability[5]	AGCV[6]
.12	15.9	.21	10.2

[1]) Means are ranked proportionally along the vertical lines. Treatments with the same mean are positioned at the same horizontal point on the vertical lines.
[2]) Monte de la Cruz
[3]) Bosque de la Hoja
[4]) probability of a higher value of 'F'
[5]) narrow-sense heritability, based on individual trees
[6]) additive genetic coefficient of variation

the reports mentioned above. In any case, until the reason for the inferiority of the Colombian seed orchard material is clarified, it would be imprudent to use this seed source for reforestation in Costa Rica.

The values of heritability and AGCV are within the ranges typically found for these traits in progeny tests of forest trees (CORNELIUS, 1994), and confirm the potential for improvement of the local base population.

The results do not permit firm conclusions to be drawn on possible variation in growth rate at later stages. However, unless age-to-age correlations are negative, then the selection of seed sources based on juvenile growth should produce a reduction in rotation length concomitant with the increased early growth. If, as LAMBETH's (1980) results suggest, age-to-age correlations tend to be positive, then this effect will be further enhanced by more rapid growth at later stages. However, it should be stressed that early growth rate is in itself a trait of key economic importance, as improvements in early growth rate can reduce early cleaning costs and their associated high interest charges.

Conclusions

1. The Cipresal, Bosque de la Hoja, Monte de la Cruz (all north of Heredia) and La Lucha provenance – all represented by plus-trees selected for form and girth – have faster juvenile growth rate than the 3 commercial controls included. It is recommended that commercial seed collections be made from well-formed trees of better than average diameter in these stands. Seed collections from the Santa María Dota source should be avoided, as should use of seed from the La Arcadia clonal seed orchard.

2. The estimated values of the genetic parameters suggest that worthwhile gains in growth traits may be made.

3. These conclusions apply principally to the breeding zone in question, i.e. the Cordillera Central of Costa Rica, at altitudes between 1900 m and 2300 m a.s.l..

Acknowledgements

The authors thank LUIS JARA and ENRIQUE TRUJILLO (CATIE) for their constructive comments. The contributions of VICTOR ALVARADO, OLDEMAR BAEZA, GERARDO BARQUERO, CARLOS CASTRO, EUGENIO COREA, MARVIN HERNÁNDEZ, JOSÉ MASÍS, JOSÉ-ANGEL QUIRÓS and LUIS SÁNCHEZ are gratefully acknowledged, as is the financial support of the British Overseas Development Administration and the Norwegian Ministry of Foreign Affairs. The authors also thank Mr. DIEGO GUTIÉRREZ VICTORY and the other owners of Hacienda La Reunión S.A..

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A Progeny Trial with Domesticated *Picea sitchensis* (BONG.) in Denmark

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(Received 30th August 1995)

Summary

In 1972 a progeny trial with *Picea sitchensis* (BONG.) were established on 3 harsh locations in Denmark. Growth and qualitative parameters have been measured several times. Growth, stem form, wood density (pilodyne), frost resistence and resistence to aphids were found to be partly under genetic control, and the characters are mostly interrelated. The age-age correlations for growth are high, and selection could be carried out with advantage before 10 years of age.

High variation in growth within site, high plant departure and aphid attacks were found in one of the trials. Substantial genotype by environment interaction for growth parameters was revealed between this trial and the 2 trials with lower mortality.

Key words: Progeny trial, genetic correlation, *Picea sitchensis,* heritability, genotype by environment.

FDC: 232.11; 165.3; 165.4; 174.7 *Picea sitchensis;* (489).

Introduction

Sitka spruce (*Picea sitchensis* (BONG.)) is a major exotic species in Danish forestry grown on semi-fertile soils for timber