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Performance of 19-year-old provenances of *Liquidambar styraciflua* in Paraguaçu Paulista, São Paulo

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ABSTRACT - *The genetic variation in the growth of seven 19-year-old Liquidambar styraciflua provenances was studied in Paraguaçu Paulista, São Paulo State, Brazil. The trial was established in a complete randomized block design with seven provenances, four replications and twelve-tree square plots. Significant differences among provenances were detected for diameter at breast height, height and volume, indicating the possibility of increasing timber yield through selection of the most productive provenances. Genetic correlations between growth traits were high and statistically significant. The provenance from Finca las Victorias, Guatemala had the best and the provenance from Franklin, Virginia, United States the poorest performance for all traits. A growth comparison of* Pinus caribaea *var. bahamensis with the best provenance at the same site indicated that the potential of* L. styraciflua *for silviculture in the region of Paraguaçu Paulista is high.*

Key words: tree species, genetic structure, genetic correlations, tree improvement.

INTRODUCTION

Liquidambar styraciflua L. or sweetgum is a North and Central American tree species. The species occurs naturally between the latitudes 13° N to 41° N. In the USA the species is found at a variety of sites, from Connecticut southwards across the east to central Florida and eastern Texas. It occurs as far west as Missouri, Arkansas, and Oklahoma and northwards to southern Illinois. It is also found in scattered locations in northwestern and central Mexico, Guatemala, Belize, Salvador, Honduras, and Nicaragua (Kormanik 1990). In Mexico and Central America the species is frequently found at altitudes between 900 and 1,600 m (McCartur and Hughes 1984) and is considered very promising for the American tropics (McCarter and Hughes 1984). *L. styraciflua* is perhaps one of the hardwood species that adapts most easily to different soil and site conditions (Kormanik 1990). The tree grows moderately fast, is highly resistant to insect attack and has a very straight trunk. This large deciduous monoecious tree reaches a height of over 45 m and diameter of 1.2 m at maturity (Kormanik 1990). Its multi-purpose wood can be used for pulp, railway sleepers, saw log, furniture, firewood, and is of special value in veneer and plywood industries (McCartur and Hughes 1984, Kormanik, 1990).

As a result of the wide natural distribution, the phenology and growth traits of *L. styraciflua* vary significantly among seed sources (Shimizu 2005). The species has a promising potential for silviculture in Brazil. Experiments at different sites have demonstrated a potential for wood production on small stands in south and

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southeastern Brazil (Shimizu 2005). The southern (Central American) seed sources have proved to be far more productive than the North American (Gurgel Garrido et al. 1997, Shimizu and Spir 1999, Shimizu and Spir 2004). The productivity of the fastest growing provenances of around 40 $m^3 ha^{-1} year^{-1}$ was similar to fast-growing *Eucalyptus* species (Shimizu and Spir 2004).

Here, we study the performance of seven *L. styraciflua* provenances, 19 years after planting, for growth traits, in the region of Paraguaçu Paulista, Brazil. The objectives were to: *i*) study the genetic variation in *L. styraciflua* provenances of the main silvicultural traits in the region of Paraguaçu Paulista - SP; *ii*) study the correlation between growth traits and geographic and climatic characteristics in the species' natural occurrence area; and *iii*) classify provenances according to their silvicultural performance.

MATERIAL AND METHODS

Provenances and experimental site

The open-pollinated seeds for this trial were collected from trees of the seven *L. styraciflua* provenances in Central and North America (Table 1) by the Oxford Forestry Institute, UK. The geographic and climatic characteristics of the origin of the provenances are given in Table 1. The provenances were tested in 1987 at an experimental station in Paraguaçu Paulista, São Paulo State, Brazil (lat 22° 25' S, long 50° 35' W, 490 m asl). At the station the mean annual rainfall is 1,131.1 mm (maximum mean monthly temperature 22 °C and minimum 10 °C) and the soil is a dark red Latosol. The trial was arranged in a complete randomized block design with seven provenances, four replications, square plots of twelve trees spaced 3 x 2.5 m, with two external border rows. Seven years after planting, 40% of the trees in the trial were randomly thinned to about seven trees per plot (Gurgel Garrido et al. 1997). The trees were evaluated 19 years after planting for diameter at breast height (dbh), total tree height (h), and cylindrical volume (vol).

Statistical analysis

The analysis of variance was carried out at the individual tree level, based on the following statistical model:

$$Y_{ijk} = m + b_j + t_i + e_{ij} + d_{ijk},$$

where Y_{ijk} is the phenotypic value of the k^{th} individual of the j^{th} block of the i^{th} provenance; m is the fixed effect of the general mean; b_j is the fixed effect of the j^{th} block; t_i is the random effect of the i^{th} provenance; e_{ij} is the random effect of the interaction between the i^{th} provenance and the j^{th} block (error among); d_{ijk} is the random effect of the error within the provenance; $j = 1....J, J = 4$ (J is the number of blocks); $i = 1:..I, I = 7$ (I is the number of provenances); $k = 1....K$, (K is the number of trees per plot).

F tests of the analyses of variance were obtained using the GLM procedure of the statistical program SAS (SAS 1989). Components of variance were estimated by the REML (Restricted Maximum Likelihood) method in combination with the VARCOMP procedure of SAS, as the experiment was unbalanced by the unequal number of trees per plot. The estimated components of variance were: σ_p^2 = variance among provenances; σ_e^2 = environmental variance; σ_w^2 = phenotypic variance within provenances. The genetic divergence among provenances was estimated as an intra-class correlation by:

$Q_{sr} = \frac{\sigma_p^2}{2\sigma_w^2 + \sigma_p^2}$ (Merilä and Crnokrak, 2001).

Genetic correlations (r_g) between traits were estimated using the equation: $r_g = \sigma_{pxpy} / \sqrt{\sigma_{px}^2 . \sigma_{py}^2}$, where σ_{pxpy} is the genetic covariance among provenance of the traits x and y; σ_{px}^2 and σ_{py}^2 are the genetic variances among provenances for the traits x and y, respectively. Genetic covariances were estimated from the analysis of covariance using SAS.

Standard linear correlations (r) between traits and geographic and climatic characteristics of the provenance sites were estimated using the procedure REG of SAS (SAS 1989).

RESULTS AND DISCUSSION

Genetic variation within and among provenances

The F test of the analysis of variance did not detect significant differences among blocks for any of the traits under study (Table 2), indicating environmental homogeneity (probably soil). The analysis of variance showed significant differences among *L. styraciflua* provenances for all study traits (Table 2), suggesting the possibility of selecting the most productive provenances to attain higher timber yields.

Table 1. Geographic coordinates, altitude, annual rainfall, and temperature of the provenance sites of *L. styraciflua* seed collections in Central and North America

Number	Provenance	Latitude N	Longitude W	Altitude (m)	Annual rainfall (mm)	Temperature (°C) (annual mean)
1	Los Alpes, Siguetepeque – Honduras	14° 33'	87° 58'	1,275	1,500	18.0
2	Tatulé – Honduras	14° 12'	87° 50'	1,550	1,750	—
3	Las Lajas, Comayagua – Honduras	13° 48'	87° 34'	1,150	2,000	21.5
4	Finca las Victorias, Sierra de Las Minas - Guatemala	15° 12'	89° 22'	900	2,079	20.0
5	Tactic, Coban – Guatemala	15° 19'	90° 21'	1,400	1,900	17.5
6	Montebello, Chiapas – México	16° 04'	91° 44'	1,500	1,175	18.0
7	Franklin, Virgínia – EUA	36° 04'	76° 30'	30	1,175	—

Table 2. Estimated mean squares, *F* test results and components of variance for dbh, height and volume of 19-year-old *L. styraciflua* provenances. (σ_p^2 = genetic variance among provenances; σ_w^2 = phenotypic variance within provenance; Q_{ST} =genetic divergence among provenances)

Source of variation	df	dbh (cm)	Height (m)	Volume ($m^3\,tree^{-1}$)
Block	3	65.0211	45.8275	0.1755
Provenance	6	883.9689 **	311.4389 *	3.9391 **
Error	171	70.1099	26.8424	0.3366
σ_p^2		44.2348	16.9661	0.1831
σ_w^2		70.0738	26.9046	0.3341
Q_{ST}		0.2399	0.2397	0.2151

** P<0.01; * P<0.05

The genetic divergence among provenances (Q_{ST}, Table 2) was estimated at 24% for dbh and for height and at 21% for volume, indicating that most of the genetic variation is found within provenances. However, these values are higher than those observed by Gurgel Garrido et al. (1997) seven (maximum 1%) and ten (maximum 2%) years after planting. The increase in genetic differentiation of the traits between the 10th and 19th year indicates an increased genetic expression of the traits in the provenances. The same tendency of increased genetic differentiation among provenances with increasing age was observed in *Araucaria cunninghamii* (Sebbenn et al. 2005). The same study shows that the greater genetic variation among provenances is an expression of the natural selection pressure, which favors the growth of the most adapted and disfavors the less adapted provenances.

Provenance performance

The provenances varied in growth (Table 3). Of the 19-year-old provenances, Finca las Victorias from Guatemala performed best for dbh, height and volume and Las Lajas from Honduras second best for all studied traits, indicating these two as the best-suited provenances for Paraguaçu. According to the standard deviation, the two provenances have statistically significant means for dbh and volume. Franklin (EUA) performed worst for all studied traits was, followed by Tactic (Guatemala), and Montebello (Mexico). According to the standard deviation, the trait means of Franklin differ statistically from all other provenances. The same was observed for Tactic. The relative differences between the best and second best provenances for dbh, height and volume were 18, 3 and 29%, respectively, and the relative differences between the best and worst provenances were 76, 58 and 95%, respectively. In a previous analysis of this trial, seven and ten years after planting, the provenances Finca las Victorias and Las Lajas were the best and Franklin the worst (Gurgel Garrido et al. 1997). In our study the provenances were ranked practically in the same order (Figure 1) as in the above-cited trial, indicating the potential for early selection of seven-year-old trees. Four and nine-year-old provenances of Finca las Victorias further performed best for height and second best for dbh in Agudos, São Paulo State (Shimizu and

Table 3. Estimated means (± standard error) of dbh, height, and volume of 19-year-old *L. styraciflua* provenances

Provenance number	dbh (cm)	height (m)	volume (m^3 $tree^{-1}$)
Los Alpes – Honduras	21.50 ± 1.39 (3)	18.27 ± 0.92 (3)	0.834 ± 0.095 (3)
Tatulé – Honduras	21.13 ± 1.51 (4)	18.20 ± 0.89 (4)	0.856 ± 0.094 (4)
Las Lajas – Honduras	22.27 ± 1.63 (2)	18.35 ± 1.07 (2)	0.975 ± 0.117 (2)
Finca las Victorias – Guatemala	27.29 ± 1.90 (1)	18.85 ± 0.86 (1)	1.381 ± 0.157 (1)
Tactic – Guatemala	11.64 ± 2.03 (6)	11.27 ± 1.47 (6)	0.206 ± 0.064 (6)
Montebello – México	18.87 ± 1.28 (5)	17.17 ± 1.07 (5)	0.629 ± 0.072 (5)
Franklin – EUA	6.57 ± 1.28 (7)	7.87 ± 0.73 (7)	0.064 ± 0.046 (7)
Mean	20.34 ± 2.66	16.96 ± 1.64	0.822 ± 0.172

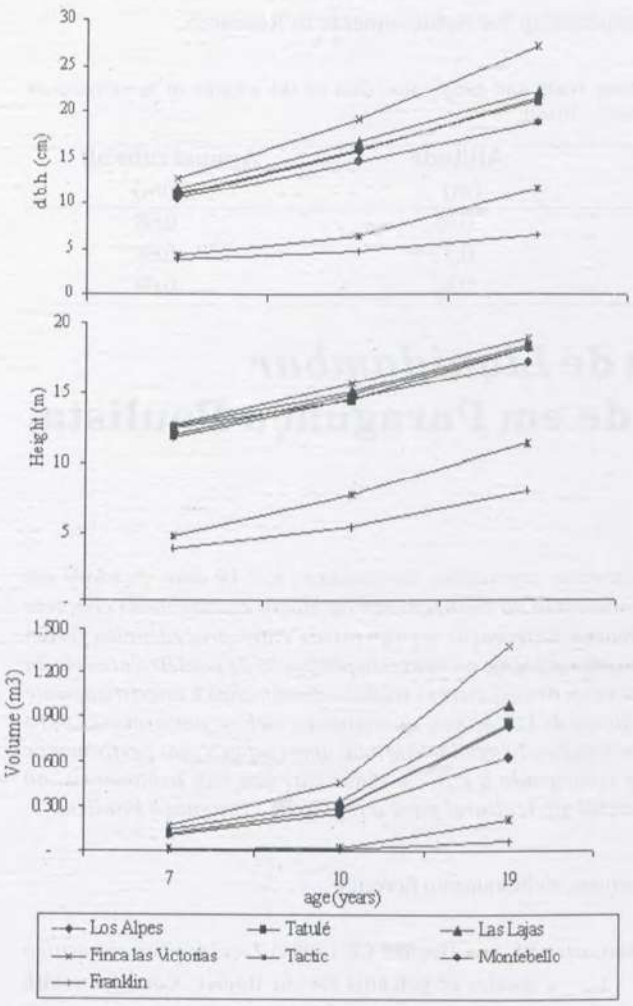

Figure 1. Dbh, height, and volume of *L. styraciflua* provenances after 7 and 19 years

Spir 1999), and 11-year-old trees in Quedas do Iguacu, Paraná State, for height and volume (Shimizu and Spir 1999). In these studies, Las Lajas ranked among the four best provenances as well. These results indicate that tree breeding programs and commercial reforestation with *L. styraciflua* in the cited regions should be based on Las Lajas.

In a comparison of the best 19-year-old *L. styraciflua* provenance (mean dbh 27.29 cm, height 18.85 m, and volume 1.381 m^3 $tree^{-1}$) with a 16-year-old *Pinus caribaea* var. *bahamensis* tree in Paraguaçu Paulista (dbh=22.73 cm; height=15.46 m; vol=0.660 m^3 $tree^{-1}$, personal observation), Finca las Victorias provenance has high growth and silvicultural potential at this site. But in a comparison of Finca las Victorias with 23-year-old *C. alliodora* provenances (Sebbenn et al. 2007) (mean height 8.83 m, dbh 11.74 cm, and volume 0.047 m^3 $tree^{-1}$) at the Experimental Station Luiz Antonio, São Paulo State, the growth of *L. styraciflua* was very fast, which shows that the species has potential for silviculture in the region of Paraguaçu Paulista. Comparing the growth of the *L. styraciflua* provenance Finca las Victorias with the exotic conifer *Araucaria cunninghamii* (Sebbenn et al. 2005) at 20 years of age at the Experimental Station Luiz Antonio, SP (height=19.68 m; dbh=19.25 cm), confirmed the fast growth of *L. styraciflua* and showed the suitability of the species for commercial timber reforestation in that region.

Correlations between traits and geographic and climatic characteristics

The standard Spearman correlation coefficient was used to study associations between growth, shape and survival traits with geographic and climatic characteristics of the provenance sites. There was a significant positive correlation between height and altitude (Table 4). This indicates that provenances from high altitudes performed better in Paraguaçu than provenances from lower altitudes. Still, although the

correlations between the traits and mean annual rainfall were relatively high (minimum 0.68, Table 4), the correlation values were not statistically different from zero at 95% probability. The correlations were however marginally significant (90% probability), suggesting that the rainfall at the original provenance site affected the performance of the provenances at the studied site. The most likely cause of the low statistic probability associated to the relative high coefficient of correlations is the low number of provenances used here.

The positive and statistically significant genetic correlations for all trait pairs (dbh and height, $r_g = 0.97$; dbh and volume, $r_g = 0.98$; height and volume, $r_g = 0.88$, $P<0.01$) demonstrated the possibility of indirect selection for one trait based on direct selection targeting another.

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Table 4. Estimates of the coefficient of Spearman correlation (r) among traits and geographic data of the origins of *L. styraciflua* provenances at the Experimental Station of Paraguaçu Paulista, São Paulo, Brasil

Trait	Latitude S	Longitude W	Altitude (m)	Annual rainfall (mm)
dbh	0.36	0.08	0.45	0.68
height	0.49	0.20	0.77 *	0.68
Volume	0.33	0.01	0.32	0.69

Desempenho de procedências de *Liquidambar styraciflua* aos 19 anos de idade em Paraguaçu Paulista, São Paulo

RESUMO - *A variação genética de sete procedências de Liquidambar styraciflua foi estudada aos 19 anos de idade em Paraguaçú Paulista no estado São Paulo, Brazil. O ensaio foi estabelecido no delineamento de blocos casualizados com sete procedências, quatro repetições e parcelas quadradas de 12 árvores. Diferenças significativas entre procedências foram detectadas para d.a.p., altura e volume cilíndrico, sugerindo a possibilidade de aumento da produção de madeira através da seleção das procedências mais produtivas. As correlações genéticas entre os caracteres estudados foram altas e estatisticamente significativas. A procedência da Guatemala, Finca las Victorias, Sierra de Las Minas, apresentou a melhor performance para todos os caracteres estudados, enquanto a procedência dos Estados Unidos, Franklin, Virginia, apresentou a pior performance para todos os caracteres. O crescimento da melhor procedência comparado à espécie* Pinus caribaea *var. bahamensis, no mesmo sítio experimental sugere que* L. styraciflua *tem alto potencial silvicultural para a região de Paraguaçú Paulista.*

Palavras-chave: espécies arbóreas, estrutra genética, correlações geneticas, melhoramento florestal.

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