WOOD DENSITY OF FOUR-YEAR-OLD CLONES OF *EUCALYPTUS GRANDIS* FROM SIXTEEN TRIALS IN COLOMBIA

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ABSTRACT

Following final evaluation for growth and form factors, selected clones of *Eucalyptus grandis* were sampled at age four years for wood density. Statistically, sites were significantly different, as were clones within sites. The correlation between ortet and clone was significant ($r = 0.648$, $P < 0.001$) and indicates that selection for wood density in the ortets will result in gain in the clones. The rank correlation coefficients of wood density to total height and volume per hectare was $r = 0.057$ and $r = 0.025$, respectively. These nonsignificant correlations indicate that there is no correlation between rate of growth (height and volume per hectare) and wood density. The mean wood density of the sampled trees was 411 kg/m^3 on an oven-dry basis.

Keywords: *Eucalyptus grandis,* wood density, clones.

INTRODUCTION

The emergence of eucalyptus pulp as a very acceptable furnish in a variety of paper-making applications is well established (Sidaway 1988; Zobel 1988). In order to improve the availability of short fiber raw material, Smurfit Carton de Colombia (SCC) began a clonal program with *Eucalyptus grandis* in 1987 (Lambeth and Lopez 1988). Trial results, including the evaluation of growth and form characteristics, have been previously reported by Lambeth et al. (1991) and Wright et al. (1991). For the operational plantation program, the clones presently in use are yielding 40% more wood volume than seedlings. As important as the clone selection process, have been nursery developments to allow for rapid and cost-effective techniques for clonal production (Arbelaez and Endo 1992).

One further aspect to be evaluated from these clones is the variation in wood density. Variation in wood density between clones or seedling progeny of *E. grandis* is well documented in South Africa (Malan 1988) and Brazil (Ikemori et al. 1986). Wood density, along with growth rates in cubic meters, will be important in determining the tons of wood that a given hectare is capable of producing.

When evaluating wood density in *E. grandis* or other members of this important genus, the end use must be considered. For example, Vital et al. (1986) found that wood density was negatively correlated with charcoal yield for *E. grandis* at 30 months of age in Brazil. There is some controversy as to the importance of wood density in terms of pulp yield, kappa number, and paper strength traits. Vasconcellos Dias and Claudio-da-Silva (1985) conclud-

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TABLE 1. *Description of the site conditions for 16 clonal trials of* E. grandis *in Colombia.*

Site	Number of trials	Altitude (m)	Mean temperature (°C)	Mean rainfall (mm/annum)
Juliana	3	1,750	18	2,046
Retiro	6	1,750	18	2,046
San Jose	3	1,750	18	2,046
La Suiza	4	1,560	20	1,055

ed that in *E. grandis* "Wood densities beyond a certain level may result in an undesirable combination of paper properties, for most end-users." In South Africa, Arbuthnot (1991), in a study which included *E. grandis* and three other species of eucalypts, stated: "Wood density is highly correlated with a number of pulp properties and paper parameters." Sampling strategies based on age, species, and genetic components of plantation wood for the desired end product(s) are mandatory where an economic return on investment is required.

MATERIALS AND METHODS

A total of 1,100 phenotypic selections (ortets) of *E. grandis* were made in plantations covering 1,500 hectares. At the time of selection, a wedge of about 60-g dry weight was taken at breast height (1.4 m above ground). Wood density from each ortet was then determined, using oven-dry weight and green volume. Wood density, however, was not included as a selection criterion. The average wood density of the ortets was 435 kg/m^3 (range of 254 kg/m^3 to 732 kg/m^3) with a coefficient of variation of 11.4%.

The cloning process at SCC has been documented among others (Wright 1992; Arbelaez and Endo 1992). Final evaluations of 460 clones in 16 trials (Table 1) were made at age three years (Lambeth et al. 1991). From these third-year evaluations, 65 clones were selected based on volume growth, tree form, crown vigor, and branching characteristics.

At the end of the fourth growing season, one replication in each of the 16 trials was sampled for wood density. Each clone was represented by a maximum of ten trees. From each tree, a 5-mm increment core was removed at breast height. Wood density was then determined using green volume and oven-dry weight.

RESULTS AND DISCUSSION

The wood density data were analyzed using analysis of variance, and results from individual trials are presented in Table 2 with the across site analysis presented in Table 3. Clones differed significantly ($P < 0.001$) in each of the 16 individual trials. The analysis across sites showed that both sites and clones within sites differed significantly ($P < 0.001$). However, the significant difference between sites must be interpreted with caution since clone representation differed between sites. Replicated trials established on seven sites in 1991 with the 65 selected clones will help to clarify possible genotype by environment interaction in wood density and other traits.

The mean wood density of a clone at age four years was compared to the total height and volume per hectare values at age three years. The rank correlation coefficient of wood density to total height was $r = 0.057$; and for volume per hectare, the correlation with wood density was $r = 0.025$. These nonsignificant correlations indicate that there is no correlation between rate of growth (height and volume per hectare) and wood density for the clones and sites evaluated.

The correlation coefficient of the wood density of the ortet with that of the clones was $r = 0.648$. This value was significant ($P < 0.001$) and indicates that to a certain degree, selection for wood density in the ortet will result in gain in the clones. Jesus and Vital (1986) also found that at age 31 months, there was a significant correlation between ortet wood density with that of the clones in *E. grandis* in Brazil. The mean wood density of the ortet was 435 kg/m^3 compared to 411 kg/m^3 for the clones. This difference probably reflects the older age of the ortets ($\pm$ 10 years).

Two of the trials (La Suiza 1 and Retiro 1) had a total of 22 clones in common. The rank correlation coefficient ($r = 0.842$) for wood density of the clones at the two sites was significant ($P < 0.001$) and indicates stable clonal

TABLE 2. *Statistical analysis of wood density from 16 trials of* E. grandis *clones in Colombia. Mean square values (MS) followed by *** differ statistically at the 0.001 level.*

Site	Source	df	MS	Trial mean (kg m $^{-3}$)	Coefficient variation (%)	Density range (kg m $^{-3}$)
Juliana 1	Clones	19	0.00856***	391	3.5	339–454
	Residual	161	0.00018			
Juliana 2	Clones	42	0.01316***	397	3.1	328–482
	Residual	337	0.00015			
Juliana 3	Clones	39	0.00727***	403	2.8	349–471
	Residual	307	0.00012			
Retiro 1	Clones	31	0.01083***	434	3.0	371–514
	Residual	271	0.00017			
Retiro 2	Clones	38	0.00991***	409	2.8	356–509
	Residual	330	0.00013			
Retiro 3	Clones	37	0.01287***	411	2.7	345–496
	Residual	307	0.00012			
Retiro 4	Clones	31	0.00996***	420	2.4	347–472
	Residual	264	0.00010			
Retiro 5	Clones	31	0.00902***	413	2.8	362–474
	Residual	260	0.00013			
Retiro 6	Clones	28	0.01254***	423	2.7	347–494
	Residual	236	0.00013			
San Jose 1	Clones	37	0.01146***	420	3.3	340–512
	Residual	283	0.00019			
San Jose 2	Clones	39	0.00879***	416	4.1	358–490
	Residual	313	0.00030			
San Jose 3	Clones	25	0.01204***	424	3.7	351–506
	Residual	196	0.00024			
La Suiza 1	Clones	35	0.01051***	417	4.2	354–501
	Residual	283	0.00031			
La Suiza 2	Clones	36	0.01336***	400	4.1	319–478
	Residual	286	0.00027			
La Suiza 3	Clones	32	0.01216***	395	3.3	329–472
	Residual	279	0.00017			
La Suiza 4	Clones	35	0.01412***	401	4.1	337–477
	Residual	284	0.00028			

performance for wood density across the two sites. Lambeth et al. (1991) observed that volume growth was also consistent for clones planted on the two sites.

TABLE 3. *Statistical analysis across sites of wood density from 16 trials of* E. grandis *clones in Colombia. Mean square values (MS) followed by *** differ statistically at the 0.001 level.*

Source	df	MS	Overall mean (kg m $^{-3}$)	Coefficient variation (%)	Density range (kg m $^{-3}$)
Site	3	0.12705***			
Clone (site)	526	0.01155***	411	3.5	319–514
Residual	4,418	0.00021			
Total	4,947				

In Table 4 the wood density values of the selected clones are presented. The coefficient of variation of wood density in the seedling check lots was generally higher than that for clones, indicating that seedlings were more variable. The wood density of the seedling source from South Africa was considerably below that of many of the clones and the seedling sources from Colombia (Claridad and Chupillauta). In twelve of the sixteen trials, there were clones that were significantly higher for wood density than seedlings.

CONCLUSIONS

The mean wood density of the sampled trees was 411 kg/m^3 on an oven-dry basis. This wood

TABLE 4. *Wood density values of selected clones compared to seedling check lots (Claridad, Chupillauta, Republic of South Africa) including the coefficient of variation (CV). In each trial mean density values followed by the same letter do not differ statistically when compared using the Duncan-Waller test.*

Site	Clone	Mean density (kg m $^{-3}$)	CV (%)	Site	Clone	Mean density (kg m^{-3})	CV (%)
Juliana 1	MES1002	454 a	3.0		CLARID.	411 c	3.1
	CHUPIL.	407 b	2.7		MES0107	407 c	2.8
	MES0908	405 b	3.1		SUE2505	358 d	3.2
	SUE1601	402 b	3.3	La Suiza 4	SUI2501	477 a	4.5
	CLARID.	401 b	4.5		SUE0301	474 a	1.1
	MES0103	383 c	4.1		SUI1902	434 b	2.6
	SUI0801	381 c	3.6		BPO0117	422 c	3.8
	CL10909	356 d	4.2		CLARID.	419 c	7.0
	ES15824	340 e	3.4		CL10528	402 d	5.5
Juliana 2	MES0513	483 a	3.8		CL10951	396 d	4.9
	CHUPIL.	421 b	3.8		RSA	369 e	5.3
	CLARID.	408 c	2.9		ALA1105	S84 e	2.5
	MES0903	401 d	3.2		CL10404	35 e	3.8
	MES0907	399 d	3.0		CL10935	349 f	2.5
	CL10502	394 d	4.2		SUI0903	337 g	2.8
	MES0902	384 e	1.3	Retiro 1	BPO0117	451 a	2.6
	CL10922	380 e	2.5		EST0104	438 b	2.8
	CL10932	377 e	3.5		SUI2401	426 c	3.4
	CL10816	376 e	2.0		SUI4610	406 d	3.3
	CL10942	373 e	1.3		CHUPIL.	394 e	3.0
	SUI1904	370 f	3.6		RSA	391 e	3.9
	CL10902	357 g	3.5	Retiro 2	MES1009	460 a	2.7
	CL10938	332 h	2.5		BPO0104	438 b	2.4
Juliana 3	CLARID.	451 a	3.0		CL10529	426 c	1.2
	MES0911	441 b	2.6		CL11305	422 c	2.0
	MES0914	405 c	1.4		SUI0902	408 d	5.1
	MES0703	405 c	3.9		RSA	394 d	2.0
	MES0517	397 d	1.3		ALA1105	389 e	2.3
	CL10930	393 d	2.1		SUI0903	388 e	2.5
	SUE0402	392 d	1.0		CL10637	381 e	2.6
	CL10641	388 e	2.5		CHUPIL.	371 f	4.2
	RSA	381 d	2.4	Retiro 3	CHUPIL.	478 a	2.7
La Suiza 1	SUE2206	409 a	5.1		MES0203	454 b	2.2
	SUI0602	408 a	1.7		SUI3104	443 c	2.6
	CHUPIL.	403 b	4.6		SUI1903	440 c	2.1
	RSA	400 b	7.1		SUI1901	418 d	1.0
	CL11305	398 b	5.6		CLARID.	404 e	4.6
	SUI4610	396 b	3.6		SUE2102	400 e	2.4
	CL40305	394 b	3.6		ALA1005	384 f	2.9
	SUE0108	383 c	3.7		SIN1623	382 f	3.2
La Suiza 2	SUI4701	453 a	3.6		ALA0905	378 f	4.6
	SUE0118	430 b	2.9		ALA0902	377 f	2.2
	CHUPIL.	413 c	2.8	Retiro 4	MES0705	465 a	2.6
	SUI4603	405 c	3.5		CHUPIL.	445 b	1.7
	CLARID.	404 c	4.1		CLARID.	430 c	2.6
	BAT0103	368 d	5.4		CL10906	392 d	2.0
	SUI2204	334 e	6.0		CL10688	384 e	3.4
La Suiza 3	CHUPIL.	44? a	2.3		SIN2910	347 f	2.0
	SUE2408	430 b	4.2	Retiro 5	CL10608	465 a	2.5
	MES0709	427 b	4.4		CL10937	461 b	2.1
	CL11303	423 b	4.5		CHUPIL.	453 c	3.1

TABLE 4. *Continued.*

Site	Clone	Mean density (kg m $^{-3}$)	CV (%)	Site	Clone	Mean density (kg m $^{-3}$)	CV (%)
	CLARID.	440 d	1.7		CL10908	389 d	5.1
	CL10808	413 e	3.2		SUE0106	388 d	4.7
	CL10936	403 f	4.2		ALA0911	383 d	2.1
	CL10941	400 f	3.1	San Jose 2	MES0203	466 a	2.0
	ALA0807	398 f	2.3		MES0919	438 b	2.7
	CL10626	386 g	2.2		CL10608	433 b	4.5
	CL10912	384 g	4.1		SUI1903	427 c	3.5
	CL10927	364 h	4.3		CLARID.	425 c	6.6
Retiro 6	MES1006	492 a	2.5		SUE2204	424 c	4.9
	MES0901	471 b	2.2		CL10635	410 d	4.7
	MES0919	467 b	2.3		SIN1623	388 e	1.8
	CHUPIL.	438 c	3.4		CL10936	375 e	3.8
	SUE2204	430 d	2.7		CL10927	373 e	4.3
	CLARID.	423 d	3.5		RSA	360 f	7.6
	CL10635	418 e	2.9	San Jose 3	MES0901	456 a	3.5
	SUI1001	403 f	2.0		CLARID.	453 a	5.9
San Jose 1	MES0912	437 a	3.2		SUI1901	434 b	1.2
	CLARID.	436 b	3.9		RSA	414 c	3.7
	SUI0901	433 b	4.9		CL10808	402 d	3.5
	RSA	401 c	4.7		CL10933	400 d	3.5

density would suggest numerous uses, such as pulp, paper, and posts. The correlation between ortet and clone was significant ($r = 0.648$, $P < 0.001$) and indicates that selection for wood density in the ortets will result in gain in the clones. There was no correlation between rate of growth (height and volume per hectare) and wood density.

Following this wood density evaluation, certain clones will be screened for pulp and papermaking characteristics. Because of the cost of these evaluations, those clones with excessively low wood density will not be tested.

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