INFLUENCE OF PROVENANCE, SUBSPECIES, AND SITE ON WOOD DENSITY IN *EUCALYPTUS GLOBULUS* LABILL.

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(Received January 2000)

ABSTRACT

The wood density of *Eucalyptus globulus* was measured as basic density in 7-year-old trees from 37 provenances grown in three sites, on cores taken at breast height. The wood density was highly significantly influenced by provenance and very significantly by site. The across-site range of variation of wood density in the different provenances was between 486 kg/m^3 and 430 kg/m^3. The provenances of subspecies *maidenii* had a significantically higher density in relation to those from spp. *globulus* and *bicostata* (472 kg/m^3 vs. 448 kg/m^3 and 443 kg/m^3). No correlation between growth and density was found.

Keywords: *Eucalyptus globulus,* wood density, provenance, site, subspecies.

INTRODUCTION

Wood density is probably the parameter most widely used to characterize wood quality, because it is correlated to many physical and technological properties. In the species grown for pulp production, wood density is usually a selection parameter in the improvement programs since it is recognized that breeding only for volume growth is not sufficient and density is a hereditary trait (Zobel and van Buijtenen 1989).

At the pulp mill, high density wood will optimize use of pulp digestor capacity. However, the wood density within a species is related to anatomy and cell biometry and these characteristics will influence paper properties, namely resistance, opacity, and bulk (Hall et al. 1973; Hillis 1984). Density may also be associated with a higher content of extractives and, if this is the case, lower pulp yields and brightness will be obtained with an increase of chemical consumption.

In *Eucalyptus globulus* trees at the age of harvest for the pulp industry (10–14 years), wood density varies approximately in the range 470 to 650 kg/m^3 and selection for improved dry weight production is the practice (Valente et al. 1992; Pereira 1994; Tomazello-Filho 1987; Borralho et al. 1992).

The effect of provenance and site on wood density for *E. globulus* has not been reported. Clarke et al. (1997) studied some provenances of 9 eucalypt species and report significant

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TABLE 1. *Identification of the 37 provenances of* Eucalyptus globulus *Labill.*

Subspecies	Code of Provenance	Origin
globulus	1	Bogalheira (Portugal)
globulus	9	Felgueiras (Portugal)
globulus	19	Forest Services (Portugal)
globulus	31	Vila do Conde (Portugal)
globulus	41	Herdade da Agolada (Portugal)
globulus	48	Monte das Flores (Portugal)
globulus	20	Pontevedra (Spain)
globulus	36	Huelva (Spain)
globulus	44	Coruña (Spain)
globulus	13	Campus Berkeley (USA)
globulus	5	St. Helens (Tasmania)
globulus	6	Rheban (Tasmania)
globulus	7	Flinders Isl. (N) (Tasmania)
globulus	10	Pepper Hill (Tasmania)
globulus	11	Henty River (Tasmania)
globulus	12	Swansea (Tasmania)
globulus	15	The Barnback (Tasmania)
globulus	16	Royal George (Tasmania)
globulus	17	Pelverata (Tasmania)
globulus	21	Seymour (Tasmania)
globulus	23	Geeveston (Tasmania)
globulus	24	Channel (Tasmania)
globulus	28	Bruny Isl. (Tasmania)
globulus	33	Taranna (Tasmania)
globulus	40	King Isl. (Tasmania)
globulus	43	Leprena (Tasmania)
bicostata	27	Toombullup (Victoria)
bicostata	4	NE Mansfiel (Victoria)
bicostata	25	21 km WEE Jasper (N.S. Wales)
bicostata	37	S. Traralgon (Victoria)
bicostata	45	Callignee APM Forest (Victoria)
maidenii	29	15 km W Batemans Bay (N.S. Wales)
maidenii	35	Myrtle Mtn (N.S. Wales)
maidenii	22	SW Nelligan Bolard SF (N.S. Wales)
maidenii	26	Mt. Dromedary (N.S. Wales)
maidenii	42	Cann Valley (Victoria)
maidenii	49	Tantawanglo Mtn (N.S. Wales)

variation in wood density between provenances within a species. Varghese et al. (1995) on 10 provenances of *E. grandis* found variations between 425 and 511 kg/m^3.

In relation to site, Beadle et al. (1996) found no effect on wood density with 2 provenances grown in two sites for *E. globulus* but a significant effect for *E. nitens.* With *E. grandis* on 3 sites, Bhat et al. (1990) found no site effect on the wood density.

We report here on the effect of provenance and site on wood density for *Eucalyptus globulus* using a nondestructive sampling of 7-year-old trees, grown in 3 sites, from 37 different provenances including the subspecies *globulus, bicostata,* and *maidenii.*

MATERIAL AND METHODS

Thirty-seven provenances of *Eucalyptus globulus* Labill. were used in this study, 27 from Australia, 1 from California, 3 from Spain, and 6 from Portugal. From the Australian provenances, 5 seedlots were from ssp. *bicostata* and 6 from ssp. *maidenii.* The remaining provenances were from ssp. *globulus.* The code and geographical origin of the provenances are summarized in Table 1.

The samples were obtained from provenance trials that were established in different locations in Portugal in 1985 (Almeida et al. 1995). The experimental design used on each site was randomized complete blocks with 7 blocks and 5 plants per provenance per block. The plantations were established following the practices usually applied in eucalypt plantations, at 3 × 3 m^2 spacing.

TABLE 2. *Characterization of the 3 sites.*

	Furadouro	Núcleo Barrosas	Vale de Galinha
Latitude	39°20′N	41°18′N	40°29′N
Longitude	9°13′W	8°17′W	8°20′W
Altitude, m	50	520	550
Mean annual rainfall, mm	607	1,709	1,263
Maximum mean temperature, °C	19.5	18.6	18.3
Minimum mean temperature, °C	11.1	7.4	7.4
Soils	Eutric cambisols on sandstone	Humic cambisols on schists	Humic cambisols on schists

TABLE 3. *Wood basic density (kg/m³) for the 37 provenances of* E. globulus *measured at 7 years of age from one core sampling at bh in 7 trees per provenance in 3 sites (Furadouro, Núcleo Barrosas, and Vale de Galinha). Mean and standard deviation in parenthesis.*

Code Prov.	Furadouro	Núcleo Barrosas	Vale de Galinha	Mean
1	432 (19)	456 (36)	439 (28)	443 (12)
4	473 (37)	452 (34)	444 (35)	457 (15)
5	432 (37)	450 (62)	431 (36)	438 (11)
6	447 (33)	420 (24)	425 (26)	431 (14)
7	438 (23)	439 (28)	429 (24)	435 (6)
9	439 (15)	424 (17)	442 (38)	435 (10)
10	448 (14)	446 (31)	441 (29)	445 (4)
11	435 (25)	451 (26)	453 (32)	449 (10)
12	442 (17)	460 (35)	432 (22)	448 (14)
13	450 (25)	455 (10)	432 (24)	446 (12)
15	461 (41)	456 (21)	452 (45)	453 (5)
16	448 (51)	447 (18)	447 (27)	447 (6)
17	443 (23)	436 (28)	428 (10)	430 (8)
19	456 (27)	460 (19)	443 (35)	456 (2)
20	429 (32)	437 (21)	471 (33)	431 (22)
21	440 (53)	422 (37)	435 (33)	433 (9)
22	479 (19)	468 (44)	462 (44)	470 (9)
23	448 (30)	447 (23)	425 (27)	539 (13)
24	430 (18)	450 (16)	423 (36)	433 (14)
25	440 (28)	459 (16)	438 (10)	446 (12)
26	531 (51)	464 (16)	463 (35)	486 (38)
27	455 (37)	434 (21)	449 (21)	445 (11)
28	436 (24)	442 (25)	427 (32)	435 (8)
29	486 (35)	492 (24)	469 (39)	482 (12)
31	443 (26)	437 (11)	438 (34)	439 (3)
33	423 (31)	467 (52)	437 (16)	442 (23)
35	480 (15)	471 (34)	459 (20)	467 (11)
36	403 (89)	449 (31)	425 (19)	437 (23)
37	447 (48)	443 (21)	441 (16)	445 (12)
40	430 (40)	442 (25)	419 (34)	432 (12)
41	454 (23)	444 (14)	427 (41)	442 (14)
42	451 (29)	458 (24)	462 (38)	457 (6)
43	422 (28)	432 (19)	440 (27)	431 (9)
44	456 (11)	456 (22)	448 (15)	453 (5)
45	460 (28)	450 (31)	440 (29)	449 (10)
48	457 (33)	453 (22)	427 (41)	461 (16)
49	458 (47)	466 (21)	481 (47)	479 (12)

A nondestructive sampling was made at 7 years of age in three locations (Furadouro, Núcleo Barrosas, and Vale de Galinha) by taking cores at breast height (bh) in the N side, from 1 random tree per block for all the provenances. The location, climatic data, and soil characteristics of the 3 experimental sites are given in Table 2. The 3 locations have different quality site indices for eucalypt growth. The average total volume in the trials at 7 years of age was 101.65 m³/ha, 88.95 m³/ha, and 54.55 m³/ha, respectively, in Furadouro, Núcleo Barrosas, and Vale de Galinha. The total volume was calculated using tree dbh. and total height and an eucalypt volume equation developed for Portugal which is applicable to this tree age (Tomé and Tomé 1994).

Wood density was determined as basic density using the water immersion method for volume determination. An analysis of variance was made using the Scientific Statistical software SigmaStat© for Windows Version 2.0, from Jandel Corporation.

RESULTS AND DISCUSSION

The wood density at breast height for all provenances of *Eucalyptus globulus,* at 7 years of age, was 449 kg/m³ in Furadouro, 450 kg/m³ in Núcleo Barrosas, and 442 kg/m³ in Vale de Galinha (Table 3). These densities are lower than those reported for 10- to 14-year-old trees (Valente et al. 1992) and similar to the 460 kg/m³ reported for 8-year-old trees (Banham et al. 1995) and the 440–411 kg/m³ determined for 1-year-old trees (Pereira and Araujo 1990).

There were differences between provenances, ranging across sites between 486 kg/m³ for provenance 26 and 430 kg/m³ for provenance 17. Within a site, the range of variation of wood density was higher in Furadouro (531 kg/m³ and 403 kg/m³ for provenances 26 and 36, respectively) and lower in Núcleo Barrosas (492 kg/m³ and 420 kg/m³ for provenances 29 and 6), and Vale de Galinha (481 kg/m³ and 419 kg/m³ for provenances 49 and 40).

The ranking of provenances by wood density within each site was roughly similar for the 3 sites. For instance, provenances 22, 26, 29, and 35 were between those with the highest wood density in all sites. However, some variations in ranking between sites also occurred, i.e., provenance 20 showed one of the highest densities in Vale de Galinha but one of the lowest in Furadouro and Núcleo Barrosas.

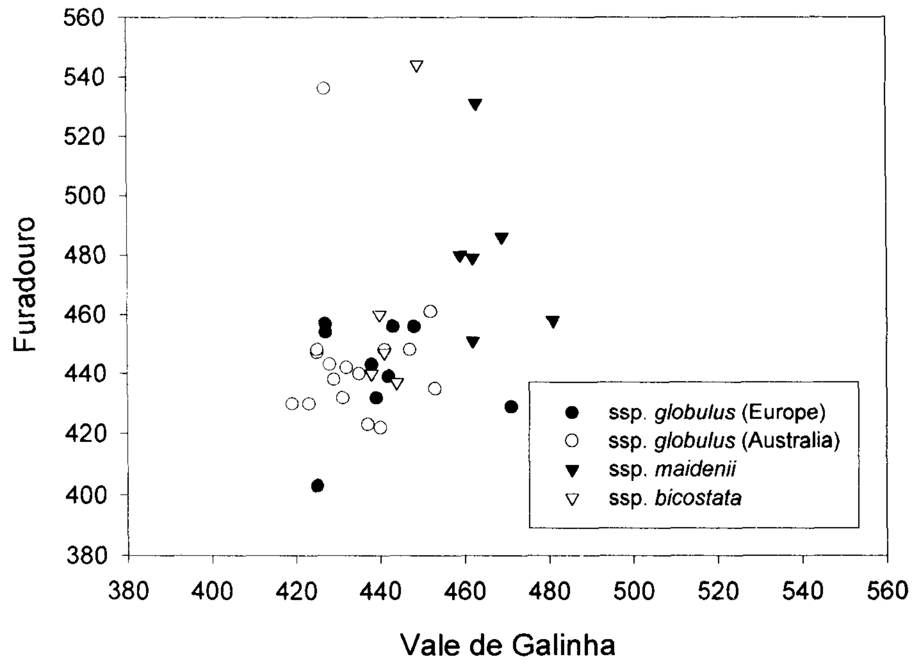

FIG 1. Relationship between wood density (kg/m^3) of each provenance of *E. globulus* trees, at 7 years of age, in Furadouro and Vale de Galinha.

The between-tree variation of wood density within a provenance and site was small. In fact, the coefficients of variation of the mean wood density determined for the 7 trees of each provenance were often near 5% and in general under 10%, with only very few exceptions.

An analysis of variance showed that provenance was highly significant ($P < 0.001$) and site very significant ($P = 0.004$) sources of variation of wood density. The interaction of provenance and site was not statistically significant ($P = 0.355$). The multiple comparison at a significance level of 5% between sites showed that wood density in Vale de Galinha was significantly different from the other 2 sites. Most provenances had lower wood density in Vale de Galinha as shown on Fig. 1 where wood density of each provenance in Furadouro and Vale de Galinha is plotted. Only 9 provenances had lower wood density in Furadouro.

The consideration of the different provenances grouped by the subspecies *globulus, bicostata* and *maidenii* and, in the case of *globulus* also subdivided by seed origin (i.e.,

TABLE 4. *Wood density of provenances of* E. globulus *at 7 years of age by subspecies* globulus *(Australia and Europe),* bicostata, *and* maidenii *as an average for the 3 sites (Furadouro, Núcleo Barrosas, and Vale de Galinha). In parenthesis the standard deviation.*

Subspecies	Furadouro	Núcleo Barrosas	Vale de Galinha	Average
globulus				
Australia	440 (14)	434 (13)	444 (11)	439 (5)
Europe	442 (19)	451 (11)	446 (13)	446 (5)
bicostata	455 (13)	442 (10)	448 (4)	448 (6)
maidenii	481 (28)	466 (11)	469 (8)	472 (8)

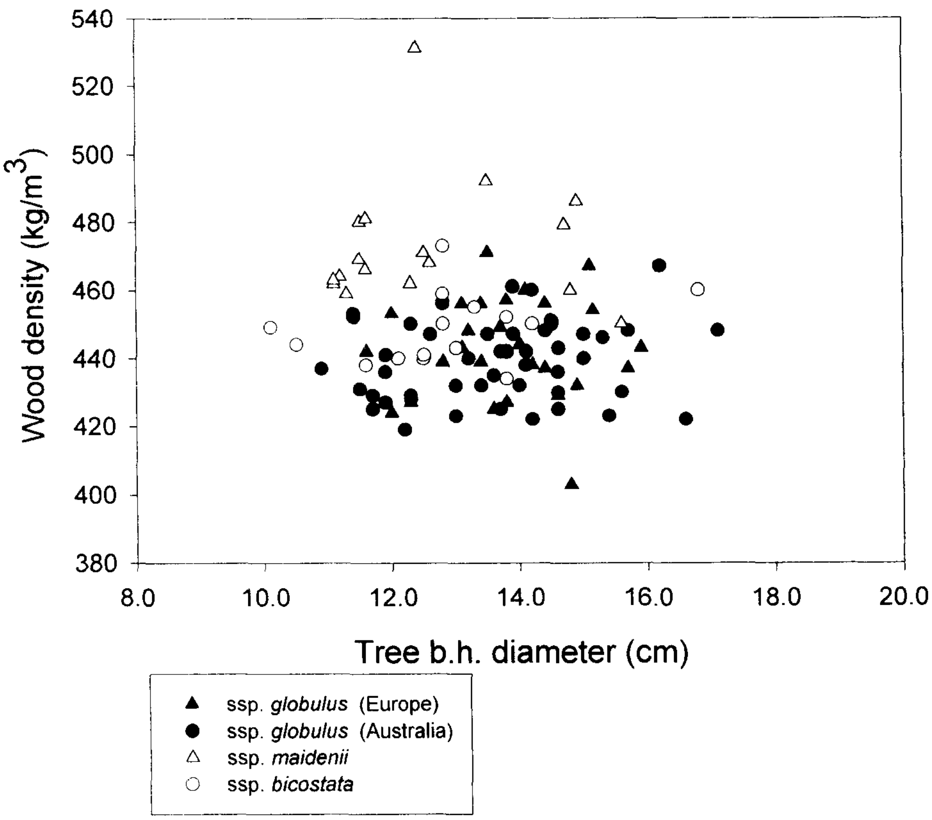

FIG 2. Relationship between wood density and tree b h diameter of 37 provenances of *E. globulus* trees, at 7 years of age, in Furadouro, Núcleo Barrosas, and Vale de Galinha.

Australia and Europe) showed that subspecies *maidenii* has the highest average wood densities across sites, while *bicostata* and *globulus* had similar values (Table 4). The analysis of variance showed subspecies as highly significant ($P < 0.001$) and site as very significant ($P = 0.070$) sources of variation. The interaction of provenance and site was not statistically significant ($P = 0.508$).

The multiple comparison of provenances showed that only the provenances 26, 29, 22, 49, 35, and 48 differed significantly from the others. All these provenances belong to subspecies *maidenii,* with the exception of provenance 48 (spp. *globulus*).

Growth within a site did not show a significant influence on wood density. No correlation could be found between wood density and tree bh diameter or height, as exemplified in Fig. 2 for Furadouro. There are few and contradictory references on the influence of growth rate on density in eucalypts. Wilkes (1984) also found that growth rate did not influence wood density in 6 eucalypt species. However, Cromer et al. (1998) using fertilization increased wood density by approximately 6% in *E. grandis,* and Megahed and El-Lakany (1983) found a significant correlation of specific gravity with growth in *E. camaldulensis.* In 1-year-old *E. globulus* trees, with different growth rates by manipulation of nutrients and water, wood density did not show a significant correlation with growth (Pereira and Araújo 1990), and the same was reported for 14-year-old *E. globulus* trees with different bh diameters due to different spacings (Ferrari and Scaramuzzi 1982).

The effect of density when selecting for dry

TABLE 5. *Ranking of provenances of* E. globulus *at 7 years of age by volume growth (m³/tree), wood basic density (kg/m³), and dry wood weight production (kg/tree) as an average for the 3 sites (Furadouro, Núcleo Barrosas, and Vale de Galinha). In bold the commercial seed lot provided by the National Forest Services (19).*

Volume growth		Wood density		Dry weight production	
Ranking	m³/tree	Ranking	kg/m³	Ranking	kg/tree
23	0.111	26	486	23	49.22
31	0.103	29	482	31	45.32
21	0.098	27	476	28	44.84
28	0.096	35	470	21	42.15
45	0.093	22	470	45	42.00
24	0.091	28	468	33	40.41
33	0.091	49	468	24	39.80
1	0.088	42	457	1	39.04
41	0.086	15	456	41	38.28
10	0.086	4	456	44	38.23
44	0.084	**19**	**456**	10	38.21
40	0.083	44	453	20	37.79
20	0.083	45	450	**19**	**36.71**
13	0.082	16	447	13	36.69
19	**0.080**	11	446	40	36.03
36	0.080	20	446	12	35.22
12	0.079	13	446	29	34.23
6	0.075	48	446	36	33.99
11	0.073	25	446	42	33.28
42	0.073	10	445	11	32.60
43	0.072	12	445	6	32.19
29	0.071	37	444	15	31.87
17	0.071	33	442	22	31.59
15	0.070	1	442	43	31.11
16	0.068	41	442	17	30.85
22	0.067	23	440	16	30.43
37	0.064	31	439	49	29.25
49	0.063	5	438	37	28.50
48	0.062	17	436	48	27.79
7	0.062	7	435	7	26.97
5	0.060	9	435	4	26.59
4	0.058	24	434	5	26.25
9	0.057	21	432	27	25.96
25	0.055	43	431	26	25.53
27	0.054	6	431	25	24.81
26	0.052	40	430	9	24.59
35	0.046	35	426	35	21.76

wood weight production is exemplified in Table 5, where the across-site ranking in volume growth, wood density, and dry wood weight is represented. Volume growth variation between provenances is much higher than density, ranging from 0.111 m³/tree for provenance 23 to 0.046 m³/tree for provenance 35. Therefore, the effect of wood density on the ranking by dry weight production is lessened, and most shifts between volume and dry weight ranking corresponded to only 2–3 positions. Considering the best 9 provenances (25% of the total), the ranking by volume and by weight was the same.

In terms of the potential increase of pulp wood supply, comparison may be made in relation to provenance 19, which corresponds to a commercial seedlot provided by the National Forest Services. When choosing the best performing provenance (provenance 23, 49.2 kg/tree), a gain of 33% would be attained. For a mix of the 9 best provenances, a mean production of 42.3 kg/tree would be attained, corresponding to more 15% production.

It should be noted that the selection efficiency would increase if trees, instead of provenances, were considered since the tree specific effect would add to the effect of provenance, and especially of subspecies.

On the other side, it must be pointed out that when the production objective is wood for pulping, other quality parameters are of relevance, e.g., fiber dimensions, chemical composition, and pulp yield; and therefore selection has to take such characteristics into account. These parameters were also included in the research outline for these *E. globulus* provenance trials, and the corresponding results will be published soon.

CONCLUSIONS

In *Eucalyptus globulus,* the mean wood density varied with provenance, subspecies, and site. The subspecies *maidenii* showed significantly higher wood density than spp. *globulus* and *bicostata.* The wood density was not associated with tree height or diameter within a site and between sites.

ACKNOWLEDGMENTS

Financial support was received from the European project AIR2-CT96-1678 (programme AIR, DG XII). We thank R. Chambel for help in field sampling and S. Gonçalves and J. Martins for laboratory assistance.

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