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Growth and Wood Quality from 32-Year-Old *Eucalyptus pellita* Owing to Chemical Characteristics of the Soil

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Abstract. In a provenance and progeny test of *Eucalyptus pellita*, installed with seeds from 25 open-pollinated progenies from Helenvale and Coen in Australia, one individual from each progeny of the two provenances was selected. Height and DBH measurements were taken forming three diameter classes. From the felled trees, a 0.10 m disk was collected at the base of each tree to obtain samples, considering the pith, intermediate and bark positions, to evaluate the density at 12% moisture (ρ12), fiber length (Fl), and fiber wall thickness (Fwt). In the canopy projections, soil samples were collected for chemical analysis. The samples were processed based on the standard methodology for anatomy and wood properties. Factor analysis did not group the soil variables with those of dendrometry, indicating no significant effect between these sets of variables. On the other hand, multivariate analysis indicates that Fwt in the intermediate position was influenced by groups of soil variables that comprise both F1 and F2 factors. Thus, we can infer that the higher values of Fwt (I) are related to lower Ca, Mg and pH and lower values of P, organic matter and cation exchange capacity. By showing statistical significance in the

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analyses, these results suggest that Helenvale should be chosen for vegetative reproduction (cloning) of the material that makes up the Batatais Forest collection based on the wood quality variables studied.
Key words: Progenies, provenances, soil characteristics, wood quality, multivariate analysis

Crescimento e Qualidade da Madeira de *Eucalyptus pellita* em Função das Características Químicas do Solo

Sumário. Num teste de procedências e progénies de *Eucalyptus pellita*, instalado com sementes de 25 progénies de polinização aberta, procedentes de Helenvale e Coen na Austrália, foi selecionado um indivíduo de cada progénie de cada procedência. A altura e o DAP foram medidos e distribuídos por três classes de diâmetro. Das árvores abatidas, foi colhido um disco de 0,10 m na base de cada árvore, amostrando as posições relativas à medula, zona intermédia e casca, para avaliação da densidade a 12% de humidade (ρ12), do comprimento das fibras (Fl) e da espessura da parede das fibras (Fwt). Foram recolhidas amostras de solo nas projeções das copas de cada árvore para análise química. Processaram-se as amostras com base na metodologia padrão para anatomia e propriedades da madeira. A análise de fatores não agrupou as variáveis do solo com as dendrométricas das árvores indicando que não existe efeito significativo entre essas variáveis. Por outro lado, a análise multivariada indicou que a Fwt na posição intermédia (Fwt I) foi influenciada pelos grupos de variáveis do solo que compõem os fatores F1 e F2. Assim, podemos inferir que maiores valores de Fwt na posição intermédia podem estar relacionados com menores teores de Ca, Mg, P e pH, e menores valores de matéria orgânica e capacidade de troca catiónica. A procedência Helenvale foi a que mostrou significância estatística nas análises devendo ser a escolhida para reprodução vegetativa (clonagem) do material que compõe o acervo da Floresta de Batatais, para as variáveis da qualidade da madeira estudadas.
Palavras-chave: Progénies, procedências, características do solo, qualidade da madeira, análise multivariada

Croissance et Qualité du Bois d'*Eucalyptus pellita* en Raison des Caractéristiques Chimiques du Sol

Résumé: Dans un test de provenance et de descendance d'*Eucalyptus pellita*, installé avec des graines de 25 descendances à pollinisation libre d'Helenvale et de Coen en Australie, un individu de chaque descendance des deux provenances a été sélectionné. Les mesures de hauteur et de DHP ont été prises pour former trois classes de diamètre. Des arbres coupés, un disque de 0,10 m a été prélevé à la base de chaque arbre, pour obtenir des spécimens en tenant compte des positions moelle, intermédiaire et écorce, pour évaluer la densité à 12% d'humidité (ρ12), de la longueur des fibre (Fl) et épaisseur de la paroi fibre (Fwt). Dans les projections de la canopée, des échantillons de sol ont été collectés pour analyse chimique. Les échantillons de bois ont été traités sur la base d'une méthodologie

standard pour l'anatomie et les propriétés du bois. L'analyse factorielle n'a pas regroupé les variables du sol avec celles de la dendrométrie, indiquant qu'il n'y a pas d'effet significatif entre ces variables. D'autre part, l'analyse multivariée indique que l'Fwt en position intermédiaire a été influencée par les groupes de variables de sol qui composent les facteurs F1 et F2. Ainsi, on peut en déduire que des valeurs plus élevées d'Fwt (I) peuvent être liées à des teneurs plus faibles en Ca, Mg et pH et à des valeurs plus faibles de P, matière organique et capacité d'échange cationique. L'origine Helenvale est celle qui a montré une significativité statistique dans les analyses et doit être choisie pour la reproduction végétative (clonage) du matériel qui compose la collection de la forêt de Batatais, pour les variables de qualité du bois étudiées.
Mots-clés: Descendances, origins, caractéristiques du sol, qualité du bois, analyse multivariée

Introduction

The 2030 Agenda of Sustainable Development Goals (SDGs) reinforces the Convention on Biological Diversity (COP15) held in China in October 2020, indicating that "biodiversity is wisely valued, conserved and restored by the year 2050, maintaining ecosystem services for a healthy planet and offering its essential benefits to all people". The restoration of ecosystems and the recomposition of vegetation must be fostered in line with strategies for the compatibility of agricultural/forest production, territorial development and biodiversity (Carta de São Paulo, 2020). The need to find new and alternative materials for the functionality of today's world makes the genetic resource of a species, or population, invaluable in the search for superior individuals in size and shape, but especially we think about wood quality in a silvopastoral or agroforestry system.

Eucalyptus is a genus of the Myrtaceae family with more than 600 described species originating, mainly, from Australia and Indonesia. Some *Eucalyptus* spp. are a perfect alternative for wood production with multiple uses and easy workability. They respond well to genetic improvement and forestry, and their cultivation is largely focused on the supply of cellulose and energy. They comprise young, short-cycle and fast-growing forests (ZANATA *et al.,* 2010). According to ANDRADE (1911; 1961), the first plants of *Eucalyptus* spp. were brought to South America by an English boat to Chile in 1823. The first species planted in Brazil, likely either *E. globulus* and/or *E. gigantea*, sparked controversy over whether the planting took place in Rio de Janeiro in 1855 or in Rio Grande do Sul in 1868. The introduction of commercial *Eucalyptus* spp. in the Brazilian territory dates from the end of 19th century in the states of Rio Grande do Sul, Rio de Janeiro and São Paulo. However, the search for a suitable commercial species came a little later, as a result of the joint work of the agronomist and forester Edmundo Navarro de Andrade and Botanist Joseph Henry Maiden (SANTOS, 2018).

According to DAVIDE (1992), *Eucalyptus pellita* is an endemic species to Northeast Queensland, Australia. It occurs in two distinct areas. To the north (Region A), it extends from the Iron Range, near the Cape York Peninsula, to the north of Townsville - Queensland (Lat. 12 45' to 19 S), and to the south (Region B), it occurs near Gladstone in Queensland to near Tathra in New South Wales (Lat. 24 to 36 45' S). The species was formally described by the Victorian botanist Ferdinand Von Mueller in 1864, who reported that it has an excellent shaft shape, reaching 40 m in height and 1 m in diameter at breast height (DBH).

Along with the Tax Incentives Law for reforestation implementation, an intensive *Eucalyptus spp.* improvement program began in 1967 with the goal of selecting superior trees (CASTRO *et al.,* 2016). The Instituto Florestal (currently Instituto de Pesquisas Ambientais - IPA), which researches the introduction of forest species, conducted the Forest Genetic Improvement Program for *Eucalyptus* spp. from 1978 onward, aiming at selecting progenies adapted to conditions of low soil fertility and evaluating/exploiting the variability of the material existing for continuous gains (GURGEL GARRIDO *et al.,* 1997).

Since then, plantations of *Eucalyptus* spp. have expanded considerably in Brazil, mainly in regions with low fertility soils, such as the Brazilian Cerrados (LIMA *et al.,* 2017). Different soil chemical compositions behave differently along the cultivated areas as a consequence of changes caused by agricultural management, among other factors (SILVA *et al.,* 2010). Thus, variation in soil quality must be understood in the context of the current management system in order to implement appropriate conservation practices (RAHMANIPOUR *et al.,* 2014; GUIMARÃES *et al.,* 2013; MUJURU *et al.,* 2013).

In the same location as the study presented here, ZANATA *et al.* (2010) assessed height, DBH, stem shape and survival at 23 years, when survival represented 69% of planted trees. The average annual increases were high in DBH (1.14 cm), height (0.89 m) and volume (0.0316 m^3/tree), indicating high silvicultural potential in this location. The coefficients of genetic variation and height heritability at the level of the progenies (h_m^2) were also high (minimum of 5.7% and 0.85, respectively), showing that this material has potential to be genetically improved via selection among progenies.

Thus, our aim was to study the processes involved in wood quality produced by *E. pellita*, targeting at the selection of provenances and progenies for vegetative reproduction (cloning). Bearing these objectives in mind, the parameters of soil chemical composition, the dendrometric survey of provenances and progenies, the determination of wood density and fiber dimensions (fiber length and fiber wall thickness) were evaluated. We hypothesized that the chemical composition of soil is uniform throughout the planting location, that provenances and progenies do not differ in terms of wood volume produced, and that there are no differences in wood quality due to chemical composition of soil and trees dendrometry.

Materials and methods

Study area

The municipality of Batatais is located between two Water Resources Management Units (UGRHI), Sapucaí-Mirim/Grande Hydrographic Basin (UGRHI 8) and Pardo Basin (UGRHI 4), in the northeastern of the State of São Paulo. The climate is classified by Köppen System as Cwa, indicating that the average temperature in the warm months is above 22°C and in the cold months below 18°C. Frosts are rare or infrequent, and water deficit is small or nil. Annual rainfall varies between 1100 and 1700 mm year^{-1}, with July being the month with the lowest rainfall and January the highest (ZANATA *et al.*, 2015). The São Bento Group, with sedimentary rocks from Piramboia and Botucatu formations, which form the Guarani Aquifer, the basaltic igneous rocks from the Serra Geral Formation, and the sedimentary deposit from the Itaqueri Formation form the geological stratigraphy of the study area (ZANATA, 2013). The subdivision adopted in the Geomorphological State of São Paulo Map shows that the region belongs to the Geomorphological Province of the Basaltic Cuestas (ZANATA and PISSARRA, 2012). Based on the Brazilian Soil Classification System (EMBRAPA, 2006; ROSSI, 2017), the area is characterized by medium textured soils, such as Dystroferric Red Latosol, Dystrophic Red Yellow Latosol, and Gleysols in alluvial floodplains. The native vegetation cover is composed of an ecological tension area between the Seasonal Semideciduous Forest and the Cerrado physiognomies (IBGE, 2012).

Collection and analysis of samples

The *E. pellita* provenance and progeny test was installed in Batatais State Forest in 1986 with (20º53'28" S and 47º35'06'' W) an average altitude of 862 meters. The 25 progenies tested resulted from the open pollination of selected parent trees from two natural populations in Australia, Helenvale (9 progenies) and Coen (16 progenies). The experimental design used for planting was that of casual blocks. The plots consisted of 25 plants, one from each progeny, with a spacing of 4 m x 4 m, with 100 repetitions. From the dendrometric data obtained in 2009 (ZANATA *et al.*, 2010) and from field observations, 25 individuals were chosen, one from each progeny. Therefore, we divided the planting area into 25 samples, consisting of 4 plots of the experimental design, leaving 4 plants to be evaluated by randomly selected progeny.

The chosen tree was free from invasive vegetation for marking geographic North, measuring DBH at 1.30 m from the ground, and felling. After felling, the total height of the tree was measured with a 50 m tape, and the basal area was measured with two crossed measures on the stump. A 0.10 m wide cylinder at the base of the felled tree stem was cut and sent for specimen preparation and analysis of density (ρ12), fiber length (Fl) and fiber wall thickness (Fwt). Along the canopy projection of each of these felled progenies, composite soil samples were collected at a depth of 0-0.20 m for chemical analyses. Phosphorus (P), organic matter (OM), pH in $CaCl_2$, potassium (K), calcium (Ca), magnesium (Mg), potential acidity (H^{+}+Al^{+3}), sum of bases (SB), cation exchange capacity (CEC) and base saturation (V%) were the variables analysed.

Wood density (ρ12)

Wood density at 12% moisture content was determined according to GLASS and ZELINKA (2010). The mass and volume at 12% moisture content (MC) were evaluated. Test pieces with 2 cm x 2 cm x 3 cm in size were conditioned at constant temperature (21°C) and 65% MC, respectively, and in these conditions, the mass was determined using an analytical balance. The volume was estimated by measuring the pieces dimensions with an external digital micrometer.

Fiber measurements

We cut small pieces of wood from each sample for maceration using Franklin's method (BERLYN and MIKSCHE, 1976). Wood fibres were stained with aqueous safranin and mounted temporarily in a solution of water and glycerin (1:1). Measurements followed the recommendations of the IAWA Committee (IAWA, 1989). Quantitative data are based on at least 25 measurements for each feature from each tree, thus fulfilling statistical requirements for the minimum number of measurements. Fiber measurements were obtained using an Olympus CX 31 microscope equipped with a camera (Olympus E330 EVOLT) and image analysis software (Image-Pro 6.3), according to SETTE JÚNIOR (2010).

Statistical methods

The results of soil analysis, dendrometric data and wood quality were submitted to multivariate statistical analysis in order to separate the processes involved in this evaluation (MOTA *et al.*, 2014; SOUZA *et al.*, 2012; ZANATA, 2013;

ZANATA *et al.*, 2015; OLIVEIRA JÚNIOR *et al.*, 2019). In studies that assess the soil and vegetation characteristics, univariate statistics are often used. Here, however, multivariate analysis was chosen to reduce the number of variables and improve the interpretation of data (SILVA *et al.,* 2020). In multivariate analysis, the factors were evaluated by Fisher's exact test with a statistical significance of 5% ($p < 0.05$). Multivariate analyses were processed in the Statistica program from Statsoft® (2007).

Results and discussion

The dendrometric data obtained in this study separated the provenances into three diameter classes for statistical analysis: the first from 0.15 to 0.22 m, the second from 0.22 to 0.25 m, and the third one from 0.26 to 0.36 m in diameter. The result of the factor analysis (Table 1) shows that the first two factors represent 49.12% of the variability contained in the original variables.

Table 1 - Eigenvalues of F1 and F2 factors for dendrometric, soil characteristics and wood quality variables obtained for the two provenances of 32-year-old *Eucalyptus pellita*, Batatais, São Paulo, Brazil. Total observations = 25

Variables	F1	F2
DBH (m)	-0.02	-0.13
Height (m)	0.03	0.27
P (mg dm^{-3})	0.06	-0.73
OM (g dm^{-3})	0.19	-0.75
pH CaCl^{2}	-0.80	0.28
K (mmol$_c$ dm^{-3})	-0.56	-0.06
Ca (mmol$_c$ dm^{-3})	-0.93	0.07
Mg (mmol$_c$ dm^{-3})	-0.88	0.01
H^{+}+Al^{+3} (mmol$_c$ dm^{-3})	0.43	-0.83
SB (mmol$_c$ dm^{-3})	-0.95	0.04
CEC (mmol$_c$ dm^{-3})	0.07	-0.89
V (%)	-0.93	0.26
ρ12 P (g cm^{-3})	0.24	0.22
ρ12 I (g cm^{-3})	0.41	0.37
ρ12 B (g cm^{-3})	0.55	0.64
Fl P (μm)	0.09	-0.57
Fl I (μm)	0.29	-0.19
Fl B (μm)	0.49	0.00
Fwt P (μm)	0.30	-0.01
Fwt I (μm)	0.74	0.28
Fwt B (μm)	0.34	0.50

The greatest variation in the sample is represented by the first factor (F1=29.83%) with direct correlation between soil variables pH, Ca, Mg, SB and V, concomitant with the inverse correlation of these F1 variables with Fwt in the intermediate position (Fwt I). The second largest variation is represented by the second factor (F2=19.29%) with direct correlation of the variables P, MO, $H^{+}+Al^{+3}$ and CEC. Emphasis is on Fl in the pith position (Fl P), which approaches this group of soil variables formed by the F2 vector and, on the other hand, wood density in the bark position (ρ12 B), which is the most distant variable of the groups formed by the two vectors F1 and F2. The independence of dendrometric variables in relation to F1 factor and of Fl C and Fwt M variables in relation to F2 factor should be highlighted. The bidimensional plane of factors F1 and F2 (Figure 1) indicates the groups formed by variables that compose the factors and the distribution of the other variables studied.

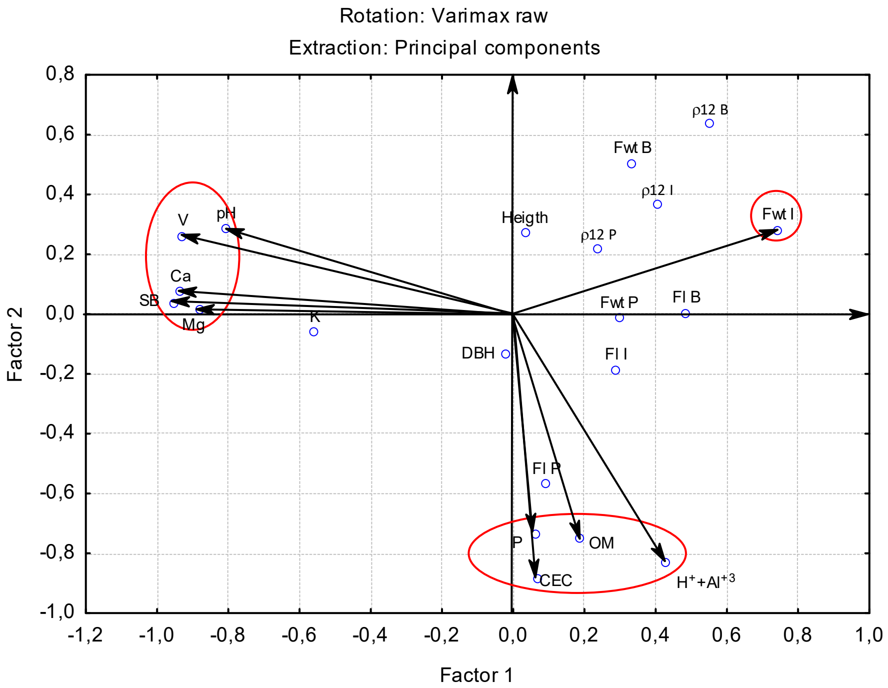

Figure 1 – Bidimensional plane of factors F1 and F2 showing the clusters of variables formed during the factor analysis and the distribution of the other variables studied

The correlation among F1 factor variables initially indicates that high soil pH values are closely associated with the amount of Ca and Mg elements, which, when added to K, result in the sum of bases (SB) and, consequently, in the saturation by bases (V%), showing that one value depends on another. At the same time, we can say with a probability of 95% of correctness that Fwt in the intermediate position (Fwt I) was inversely influenced by the groups of soil variables which compose the F1 and F2 factors.

The correlation indicated by the F2 factor complements the process contained in F1, as the low availability of bases is related to low pH value and high soil buffering power, owing to the higher exchangeable potential acidity ($H^{+}+Al^{+3}$) and, consequently, lower CEC. The mathematical and computational models studied by LIMA *et al.* (2017) showed that hydrogen potential (pH), potential acidity ($H^{+}+Al^{+3}$) and Mg, P, K, and Al contents were, in that study, crucial characteristics for growth of *Eucalyptus urograndis*. The use of buffer methods studied by PRADO *et al.* (2020) to estimate soil potential acidity indicated that the overestimation or underestimation of soil potential acidity may incur a limestone dosage error during the management of soil fertility (liming). BALBINOT *et al.* (2010), studying the intercropping between *E. tereticornis,* and *Mimosa caesalpiniifolia* and *Mimosa pilulifera*, observed a reduction in effective CEC, sum of bases, Mg, P, Ca content and base saturation (%) of the soil, while, at the same time, pH, N, Na, Al and $H^{+}+Al^{+3}$ values increased in all planting systems. These results corroborated the high exchangeable potential acidity obtained in this study at 34 years of age. Moreover, we can infer that higher values of Fwt (I) may be related to lower contents of Ca, Mg and pH, concomitant with lower values of P, OM and CEC.

According to LOPES and GUIDOLIN (1989) and based on the reference values for evaluating chemical soil characteristics (Table 2), soil analysis interpretation shows that the experimental area has very low pH and very low base saturation (V) (up to 25%), characterizing a region with high soil acidity (up to 4.3), with very low availability of cations for exchange. The average value of 21.0 g dm^{-3} (2.1%) of Organic Matter (OM) in the soil does not reach the minimum level of 50 g dm^{-3}, or 5% of OM, to be considered a sustainable soil, demonstrating the critical conditions for development of these plants. The average contents of P, K, Ca and Mg are considered low for forest species production. The potential acidity ($H^{+}+Al^{+3}$) of 36 to 55 mmolc dm^{-3}, also known as exchangeable Al or harmful acidity, has a negative effect on the normal development of a large number of cultures. When it is said that a soil has aluminum toxicity, this means that this soil has high indexes of exchangeable acidity or harmful acidity. One of the main effects of liming is to eliminate this type of acidity (LOPES and GUIDOLIN, 1989).

The analysis of variance (ANOVA) for the process contained in F1 and F2, considering provenances, diameter classes and their interaction (provenance*class), indicates a non-significant effect on both factors, *i.e.*, no significant difference is observed between provenances and diameter classes and the interaction of these treatments in relation to the variables grouped in these factors. Although the factor analysis does not discriminate the provenances according to the studied variables, the Helenvale provenance presents the highest arithmetic means of the values obtained by the chemical characteristics of the soil, including P, OM, H^{+}+Al^{+3}, CEC and wood quality (Tables 3 - 6). In Helenvale, Ca, Mg and K showed higher percentages of variation coefficient and consequently SB and V, corroborating the factor analysis. The largest standard deviation was obtained for Fl with maximum values in Helenvale.

Table 2 - Reference values for some soil chemical characteristics

Interpretation	P				K	Ca	Mg	V	Acidity
	annuals	forestry	perennials	vegetables					(pH)
	mg dm^{-3}				mmol$_c$ dm^{-3}			%	
Very low	0 – 6	0-2	0-5	0-10	0 – 0.7			0-25	>6.0
Low	7 – 15	3-5	6-12	11-25	0.8–1.5	0 – 3	0 – 4	26-50	5.6-6.0
Average	16 – 40	6-8	13-30	26-60	1.6-3.0	4 - 7	5 – 8	51-70	5.1-5.5
High	41 – 80	9-16	31-60	61-120	3.1-6.0	>7	>8	71-90	4.4-5.0
Very high	>80	>16	>60	>120	>6.0			>90	up to 4.3

Source: Soil and Plant Analysis Laboratory of the Department of Soils and Fertilizers, Faculty of Agrarian and Veterinary Sciences (FCAV) of the São Paulo State University "Júlio de Mesquita Filho" – Campus de Jaboticabal, SP, Brazil.

Table 3 - Dendrometric variables and soil characteristics of the two provenances of 32-year-old *Eucalyptus pellita*, Batatais, São Paulo, Brazil

Provenance	Progeny	Height	DBH	P	OM	pH	K	Ca	Mg	$H^{+}+Al^{+3}$	SB	CEC	V
Helenvale	93	25.60	24.0	3.0	18.0	4.1	1.1	3.0	2.0	36.0	6.1	42.1	14.5
Helenvale	94	16.95	22.0	5.0	27.0	4.1	0.9	2.0	2.0	50.0	4.9	54.9	8.9
Helenvale	97	23.05	21.5	4.0	19.0	4.2	0.7	2.0	1.0	38.0	3.7	41.7	8.9
Helenvale	128	24.70	28.5	5.0	25.0	4.0	0.7	2.0	1.0	55.0	3.7	58.7	6.3
Helenvale	129	15.60	23.5	6.0	26.0	4.0	0.7	2.0	2.0	52.0	4.7	56.7	8.3
Helenvale	131	19.30	22.5	3.0	21.0	4.3	0.4	5.0	4.0	40.0	9.4	49.4	19.0
Helenvale	132	18.90	24.5	3.0	21.0	4.1	0.4	2.0	2.0	42.0	4.4	46.4	9.5
Helenvale	133	18.60	21.0	4.0	17.0	4.2	1.0	3.0	2.0	36.0	6.0	42.0	14.3
Helenvale	134	21.40	22.5	3.0	19.0	4.2	0.7	2.0	2.0	36.0	4.7	40.7	11.5
Coen	136	20.20	18.5	3.0	21.0	4.0	1.2	3.0	2.0	42.0	6.2	48.2	12.9
Coen	137	24.70	24.0	4.0	23.0	4.2	1.0	3.0	2.0	42.0	6.0	48.0	12.5
Coen	138	20.60	21.0	3.0	20.0	4.1	0.8	3.0	2.0	42.0	5.8	47.8	12.1
Coen	139	22.90	22.0	5.0	19.0	4.1	0.9	3.0	2.0	40.0	5.9	45.9	12.9
Coen	140	18.20	23.0	3.0	20.0	4.2	0.9	3.0	2.0	40.0	5.9	45.9	12.9
Coen	141	22.50	31.0	4.0	21.0	4.1	0.6	2.0	2.0	45.0	4.6	49.6	9.3
Coen	142	15.60	30.0	4.0	19.0	4.3	1.2	5.0	3.0	38.0	9.2	47.2	19.5
Coen	143	18.15	21.0	4.0	21.0	4.1	0.9	3.0	2.0	42.0	5.9	47.9	12.3
Coen	144	18.20	25.0	4.0	21.0	4.1	0.4	2.0	2.0	42.0	4.4	46.4	9.5
Coen	145	19.00	21.5	4.0	18.0	4.1	0.5	2.0	2.0	40.0	4.5	44.5	10.1
Coen	146	18.70	15.0	4.0	19.0	4.3	0.8	4.0	3.0	36.0	7.8	43.8	17.8
Coen	147	23.30	36.0	4.0	21.0	4.3	1.2	5.0	4.0	40.0	10.2	50.2	20.3
Coen	148	28.00	29.5	4.0	20.0	4.1	0.6	2.0	2.0	40.0	4.6	44.6	10.3
Coen	150	14.30	24.0	4.0	22.0	4.0	0.6	2.0	1.0	50.0	3.6	53.6	6.7
Coen	151	20.10	22.0	4.0	25.0	4.2	0.9	3.0	3.0	36.0	6.9	42.9	16.1
Coen	152	24.60	21.0	5.0	21.0	4.3	1.3	5.0	4.0	42.0	10.3	52.3	19.7

Height (m), DBH (cm), P (mg dm^{-3}), OM (g dm^{-3}), pH ($CaCl_2$), K ($mmol_c$ dm^{-3}), Ca ($mmol_c$ dm^{-3}), Mg ($mmol_c$ dm^{-3}), $H^{+}+Al^{+3}$ ($mmol_c$ dm^{-3}), SB ($mmol_c$ dm^{-3}), CEC ($mmol_c$ dm^{-3}), V (%).

Table 4 - Wood quality variables of the two provenances of 32-year-old *Eucalyptus pellita*, Batatais, São Paulo, Brazil

Provenance	Progeny	ρ12 P	ρ12 I	ρ12 B	Fl P	Fl I	Fl B	Fwt P	Fwt I	Fwt B
Helenvale	93	0.73	0.87	0.94	636.60	1017.33	1060.12	3.58	7.25	6.80
Helenvale	94	0.55	0.58	0.80	764.81	845.56	1085.51	3.81	4.33	5.83
Helenvale	97	0.75	0.84	1.00	674.30	904.02	897.97	4.78	6.16	5.36
Helenvale	128	1.05	0.89	1.00	665.73	981.66	1125.44	4.94	6.33	6.16
Helenvale	129	0.61	0.78	0.81	844.59	937.97	784.70	4.03	4.80	5.05
Helenvale	131	0.65	0.79	0.86	539.47	716.71	625.25	3.61	3.90	5.67
Helenvale	132	0.77	0.90	0.88	613.45	761.81	718.88	4.87	5.76	6.24
Helenvale	133	0.65	0.82	0.92	642.20	790.06	808.98	3.81	4.39	4.69
Helenvale	134	0.74	0.86	1.03	693.95	849.13	1018.48	3.80	4.98	6.55
Coen	136	0.80	0.87	0.91	581.76	705.13	789.75	3.91	5.41	6.15
Coen	137	0.70	0.75	0.88	619.07	747.42	716.10	4.03	5.25	5.19
Coen	138	0.78	0.89	0.94	624.33	732.21	873.03	3.99	5.34	6.51
Coen	139	0.64	0.88	0.97	548.83	597.32	804.66	4.29	4.91	5.52
Coen	140	0.73	0.87	0.96	619.52	776.47	916.82	5.42	4.45	5.31
Coen	141	0.90	1.06	1.03	788.95	695.87	958.07	4.34	5.15	5.81
Coen	142	0.84	1.02	0.93	532.26	688.28	715.45	4.16	4.68	6.02
Coen	143	0.72	0.92	0.92	568.35	592.49	599.58	3.61	4.41	5.49
Coen	144	0.74	1.00	0.96	595.77	845.29	986.06	5.78	5.46	5.50
Coen	145	0.86	0.97	1.05	741.60	837.73	920.00	5.69	5.32	5.37
Coen	146	0.68	0.81	0.91	551.54	811.86	1041.30	3.78	3.89	6.32
Coen	147	0.66	0.69	0.84	662.88	781.42	710.67	3.52	3.63	4.34
Coen	148	0.75	0.83	1.07	440.85	717.96	862.88	3.92	5.79	6.69
Coen	150	0.64	1.16	0.94	536.51	641.37	858.18	3.74	5.71	4.82
Coen	151	0.96	0.98	1.10	616.25	751.55	972.76	4.34	5.62	6.43
Coen	152	0.92	0.82	0.74	810.00	805.07	916.89	5.48	4.42	4.92

ρ12 P (g cm^{-3}), ρ12 I (g cm^{-3}), ρ12 B (g cm^{-3}), Fl P (μm), Fl I (μm), Fl B (μm), Fwt P (μm), Fwt I (μm), Fwt B (μm)

Table 5 - Descriptive analysis of dendrometric variables and soil characteristics of the two provenances of 32-year-old *Eucalyptus pellita*, Batatais, São Paulo, Brazil

Provenance		Height	DBH	P	OM	pH	K	Ca	Mg	$H^{+}+Al^{+3}$	SB	CEC	V
Helenvale													
	Minimum	15.60	21.00	3.00	17.00	4.00	0.40	2.00	1.00	36.00	3.70	40.70	6.30
	Average	20.46	23.33	4.00	21.44	4.13	0.73	2.56	2.00	42.78	5.29	48.07	11.25
	Maximum	25.60	28.50	6.00	27.00	4.30	1.10	5.00	4.00	55.00	9.40	58.70	19.03
	Cv (%)	16.86	9.64	27.95	17.15	2.42	32.70	39.67	43.30	17.64	33.26	14.82	35.52
	SD	3.45	2.25	1.12	3.68	0.10	0.24	1.01	0.87	7.55	1.76	7.12	4.00
Coen													
	Minimum	14.30	15.00	3.00	18.00	4.00	0.40	2.00	1.00	36.00	3.60	42.90	6.72
	Average	20.57	24.03	3.94	20.69	4.16	0.86	3.13	2.38	41.06	6.36	47.43	13.43
	Maximum	28.00	36.00	5.00	25.00	4.30	1.30	5.00	4.00	50.00	10.30	53.60	20.32
	Cv (%)	17.42	21.85	14.57	8.23	2.48	31.65	34.81	33.95	8.12	32.19	6.24	30.59
	SD	3.58	5.25	0.57	1.70	0.10	0.27	1.09	0.81	3.34	2.05	2.96	4.11

Height (m), DBH (cm), P (mg dm^{-3}), OM (g dm^{-3}), pH ($CaCl_2$), K ($mmol_c$ dm^{-3}), Ca ($mmol_c$ dm^{-3}), Mg ($mmol_c$ dm^{-3}), $H^{+}+Al^{+3}$ ($mmol_c$ dm^{-3}), SB ($mmol_c$ dm^{-3}), CEC ($mmol_c$ dm^{-3}), V (%).

Table 6 - Descriptive analysis of wood quality variables of the two provenances of 32-year-old *Eucalyptus pellita*, Batatais, São Paulo, Brazil

Provenance		ρ12 P	ρ12 I	ρ12 B	Fl P	Fl I	Fl B	Fwt P	Fwt I	Fwt B
Helenvale										
	Minimum	0.55	0.58	0.80	539.47	716.71	625.25	3.58	3.90	4.69
	Average	0.72	0.81	0.92	675.01	867.14	902.81	4.14	5.32	5.82
	Maximum	1.05	0.90	1.03	844.59	1017.33	1125.44	4.94	7.25	6.80
	Cv (%)	19.86	11.89	8.98	13.04	11.71	19.76	13.53	20.91	11.98
	SD	0.14	0.10	0.08	88.02	101.55	178.44	0.56	1.11	0.70
Coen										
	Minimum	0.64	0.69	0.74	440.85	592.49	599.58	3.52	3.63	4.34
	Average	0.77	0.91	0.95	614.91	732.97	852.64	4.37	4.96	5.65
	Maximum	0.96	1.16	1.10	810.00	845.29	1041.30	5.78	5.79	6.69
	Cv (%)	13.04	13.13	9.36	15.83	10.61	14.21	17.58	13.15	11.83
	SD	0.10	0.12	0.09	97.34	77.76	121.16	0.77	0.65	0.67

ρ12 P (g cm^{-3}), ρ12 I (g cm^{-3}), ρ12 B (g cm^{-3}), Fl P (μm), Fl I (μm), Fl B (μm), Fwt P (μm), Fwt I (μm), Fwt B (μm)

Despite having the lowest values of ρ12 in the pith and intermediate positions, Helenvale it stands out in the other variables of wood quality with maximum values of Fl and Fwt in the intermediate and near to the bark positions. Coen provenance had the highest and lowest values for DBH and height, but dendrometric variables was not significant for this multivariate analysis, even though DBH was the secondary treatment.

Observing the field results (Table 4), we verified that progeny 128 (1.05 g cm^{-3}) presented a result much higher than that of Coen (0.96 g cm^{-3}) for ρ12 P. This progeny also had the highest Fl value in the bark position (Tabela 4). On the other hand, progeny 93 (Helenvale) presented the highest Fl (1017.33 μm) in the intermediate position and Fwt (Table 4) in the intermediate (7.25 μm) and bark positions (6.80 μm). The soil around progeny 128 had the lowest contents of Ca and Mg and, consequently, high soil acidity (pH=4.0); these conditions may have influenced the wood quality. MACEDO *et al.* (2013) estimated genetic parameters and genetic and phenotypic correlations in growth traits and form of *E. tereticornis* in Batatais where the Helenvale provenance had the best performance for the studied growth traits. Thus, for longer fibers and high ρ12, we should look to the Helenvale provenance, or, more specifically, the trees of progenies 93 and 128, for reproduction.

Univariate analysis of ρ12 (Figure 2) for provenances and diameter classes, with comparison of means by Fisher's test at 5% ($p<0.05$), show the results for each position (P, I and B), which must be analyzed separately. Thus, there was no statistical difference for ρ12 B in the three diameter classes, but Helenvale provenance in diameter class 3 stands out at ρ12 P.

The Coen provenance in diameter class 2 stands out at ρ12 I (Figure 2), and in diameter class 3 stands out at Fl I (Figure 3). The univariate analysis of Fwt (Figure 4) remained non-significant for the three diameter classes in each analyzed position (P, I and B). Means of wood quality variables increase from pith to intermediate positions and bark. It is possible to infer from the analysis of Table 6 that ρ12 in the pith region differs from the intermediate region and close to the bark. However, comparing intermediate and bark positions, they do not differ greatly from each other. According to ALZATE (2004), woods with characteristics of greater homogeneity in the radial direction must present better technological properties and greater use in the cutting process. For wood applications, such as cellulose and paper, lamination, or fiberboard, trees with more homogeneous wood stems are recommended owing to final product quality. For *Eucalyptus pellita* and *Eucalyptus acmenioide*, TOMAZELLO (1987) reports lower values of wood apparent density in the central region with a gradual increase towards the bark.

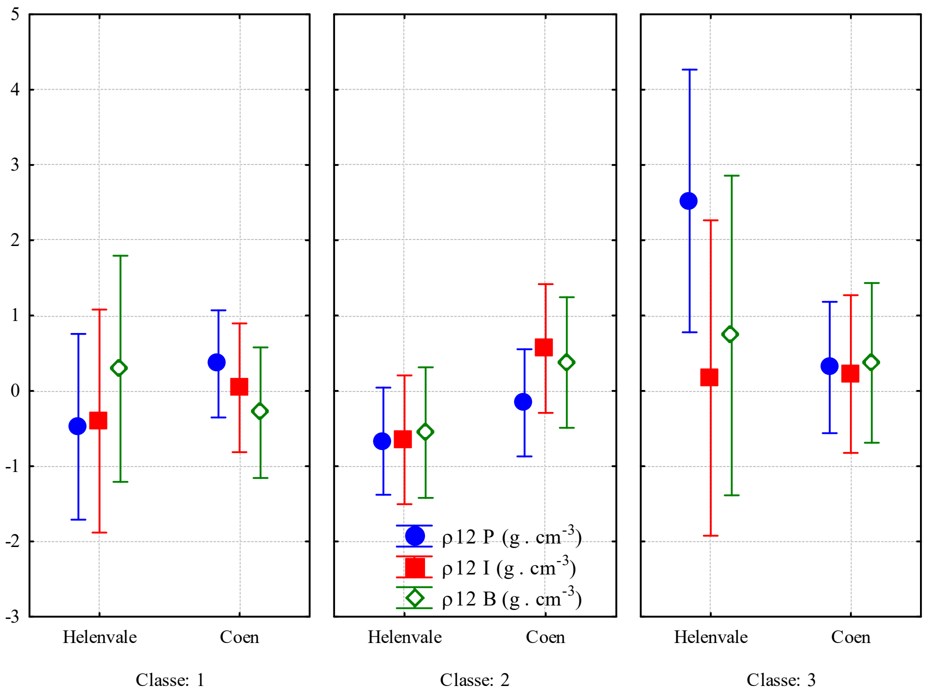

Figure 2 – Box and whisker plot of ρ12 in three positions (P, I and B) from two provenances and three diameter classes of 32-year-old *Eucalyptus pellita*, Batatais, SP, Brazil

PERTUZZATTI *et al.* (2020) observed that denser wood reaches values above 800 kg m^{-3} (0.80 g cm^{-3}), and ALVES *et al.* (2017) found a mean value of 916 kg m^{-3} (0.90 g cm^{-3}) for ρ12, both slightly below the maximum obtained by this study, showing that it is a denser wood, perhaps because it suffers the effects of water stress in the Cerrado region where it is planted. SILVA *et al.* (2019), studying mineral fertilization and wood characteristics, observed an increase in wood density in the block with partial exclusion of rainwater in the forest plantation. However, some studies report that trees planted in places with greater availability of water, compared to those of the seed provenance, present vessels with features of a drier environment (LIMA *et al.*, 2011a,b; LONGUI *et al.*, 2011).

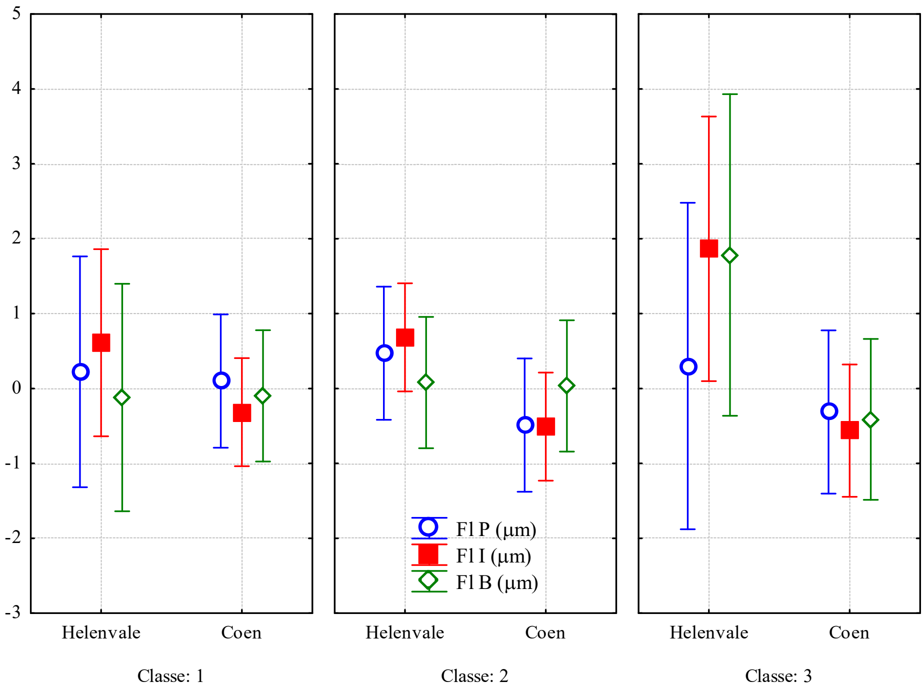

Figure 3 – Box and whisker plot of Fl in three positions (P, I and B) from two provenances and three diameter classes of 32-year-old *Eucalyptus pellita*, Batatais, SP, Brazil

According to GONZÁLES *et al.* (2014), fibers are mainly responsible for wood strength to mechanical stress. Fibers are also the most important anatomical element in cellulose production. For many decades, the relationships among fiber dimensions have been of considerable interest in interpreting cellulose and paper quality (FOELKEL *et al.*, 1978), which may help explain the results on strength of the final product and even in identification and wood/tree selection (GONZÁLEZ *et al.*, 2014). From a technological point of view, the variation in fiber dimensions is related to wood physicomechanical properties and cellulose and paper, namely by the various strength indices, fiber collapse or inter-fiber connections (TOMAZELLO FILHO, 1987).

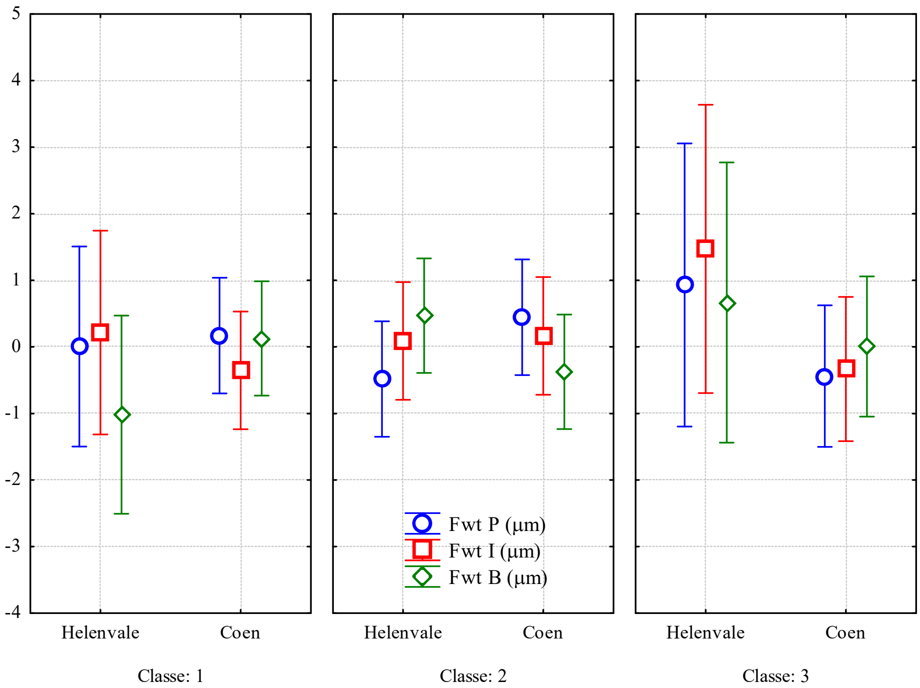

Figure 4 – Box and whisker plot of Fwt in three positions (P, I and B) from two provenances and three diameter classes of 32-year-old *Eucalyptus pellita*, Batatais, SP, Brazil

SETTE JÚNIOR (2010) obtained an average of 0.48 g cm^{-3} of ρ12 in *Eucalyptus grandis* trees at 48 months of age, indicating that the cambial meristem was forming, until this period, the so-called juvenile wood. In this case, we are measuring trees at 32 years of age, planted in 3 x 4 spacing, with other specie, *Eucalyptus pellita*, which may explain the high values of fiber density, length and thickness obtained.

SETTE JÚNIOR *et al.* (2012) show that the average length of the fibers increased (from 748 to 912 µm) over time (24 to 72 months), as did the wall thickness (from 2.0 to 3.5 µm). SILVEIRA LOBÃO *et al.* (2010) found values between 910 and 1079 µm for the fiber length and 3.95 to 5.12 µm for the wall thickness of 3 *Eucalyptus* species (grandis, urograndis and citriodora), Confirming the results obtained in this work.

Conclusions

Factor analysis did not group soil characteristics with dendrometric variables, indicating the absence of significant effect between soil and tree size.

On the other hand, with a probability of 95%, we can report that Fwt in the intermediate position was influenced by the groups of soil characteristics that composed the F1 and F2 factors. Thus, we can infer that highers values of Fwt (I) may be related to lower levels of Ca, Mg and pH, concomitant with lower values of P, OM, and CEC.

The Helenvale provenance obtained statistical significance along with the soil characteristics in the multivariate and univariate analyses, and, hence, should be used in the vegetative reproduction (cloning) of the material that were part of the Batatais Forest collection for the wood quality variables studied.

Progeny 93 from Helenvale provenance presented the highest values of Fl (1017.33 μm) in the intermediate position, and Fwt (7.25 μm) in the intermediate and bark (6.80 μm) positions. The soil around progeny 128 (Helenvale origin) had the lowest contents of Ca and Mg. Consequently, high soil acidity (pH=4.0) may have influenced the wood characteristics. Overall, then, when looking for longer fibers and higher density, we should reproduce the Helenvale provenance, specifically from trees of progenies 93 and 128.

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