SOIL ATTRIBUTES AND WOOD QUALITY FOR PULP PRODUCTION IN PLANTATIONS OF *Eucalyptus grandis* CLONE

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ABSTRACT: The soil attributes can affect the wood quality of eucalypt, which may result in considerable effect on cellulose production. This study evaluated the effect of different physical and chemical soil attributes on wood quality of *Eucalyptus grandis* for cellulose production. Five sites were selected at the Western Plateau of the State of São Paulo, planted with one clone of *Eucalyptus grandis*, with ages ranging between 6.5 and 7.0 years. Four soil types, with texture ranging from sandy to very clayey were found. At each site, three experimental plots were allocated with 100 trees each. Trees representative of each class frequency of diameter at breast height were harvested. Their biomass and wood components were characterized. The wood productivity and quality was affected by physical attributes of soil, mainly clay content, which is directly related to the amount of available water. Basic wood density did not changed at different soil types. Total lignin content decreased and holocellulose content exponentially increased as soil clay content increased (until about 350 to 400 g kg^{-1} of clay). The wood extractives content was not affected by soil attributes. Screened cellulose yield exponentially increased with soil clay content.

Key words: wood technology, eucalypt, physical characteristic, chemical characteristic

ATRIBUTOS DO SOLO E QUALIDADE DA MADEIRA PARA PRODUÇÃO DE CELULOSE EM PLANTAÇÕES CLONAIS DE *Eucalyptus grandis*

RESUMO: Os atributos edáficos podem afetar a qualidade da madeira de eucalipto, o que pode resultar em considerável efeito sobre a produção de celulose. Este trabalho teve como objetivo avaliar o efeito de atributos físicos e químicos do solo na qualidade da madeira de *Eucalyptus grandis* usada para polpação celulósica. Foram selecionadas cinco áreas no planalto ocidental do Estado de São Paulo, Brasil, plantadas com um mesmo clone de *Eucalyptus grandis*, com idades variando entre 6,5 e 7,0 anos de idade. Quatro classes de solo, com textura arenosa a muito argilosa, foram encontradas. Em cada uma das cinco áreas, foram demarcadas, aleatoriamente, 3 parcelas com 100 plantas cada. Em cada parcela, foram colhidas árvores representativas das diferentes classes de diâmetro à altura do peito para avaliação de suas biomassas e para a análise de extrativos e componentes da madeira. Os atributos físicos do solo, sobretudo o teor de argila, diretamente relacionado à quantidade de água disponível, foram os que mais afetaram a produtividade e a qualidade da madeira. A densidade básica da madeira não se alterou nas diferentes classes de solo. O teor de lignina total diminuiu e o de holocelulose aumentou exponencialmente com o aumento do teor de argila do solo (até cerca de 350 a 400 g kg^{-1} de argila). O teor de extrativos da madeira não foi afetado pelos atributos do solo. O rendimento de celulose depurada relacionou-se exponencialmente com o teor de argila do solo.

Palavras-chave: tecnologia da madeira, eucalipto, característica física, característica química

INTRODUCTION

Forestry research has driven efforts to increase wood productivity, with compatible quality to suit the needs of pulp and paper production plants. For example, genetic breeding studies, which have classically focused on wood productivity gains, turned to the quality of wood in selected genotypes, demonstrating the potential in yield gains in the pulp production process (Wright, 1991). However, studies focused on wood quality with respect to basic density have been more common (Zobel & Jett, 1995), whereas the chemical, anatomical, and physical aspects of wood are also important for pulp production.

Besides the emphasis given in breeding programs, wood quality has been studied with regard to its relation with environmental aspects, such as climatic conditions, chemical and physical soil attributes, and tree nutrition. Results have demonstrated significant environmental effects on wood quality (Ferreira et al., 1978; Tomazello Filho, 1985; Vale et al., 1995; Barcellos et al., 2005). The influence of the environment on wood quality still deserves more detailed studies, extended to the pulp production process. The practical benefits of this have been reported in several papers (Retief et al., 1997; Du Toit et al., 2001). In most of these studies, the influence of the environment on wood quality for pulp production has been characterized by very generic variables related to the quality of the location. Likewise, most studies dealing with the influence of management practices (fertilization, for example) on *Eucalyptus grandis* wood quality generically evaluate the influence or not of the practice (Higgs & Rudman, 1973; Wilkins & Kitahara, 1991; Punches & Country, 2004) or of the adoption of one or other fertilizer source (Bamber et al., 1982).

Thus, the identification of more specific variables for the site, such as soil attributes that determine wood quality is required. The objective of the present study was to evaluate the effect of different physical and chemical soil attributes on wood quality of *Eucalyptus grandis* for cellulose production.

MATERIAL AND METHODS

This study was carried out in five sites located in commercial *Eucalyptus grandis* Hill Ex Maiden (provenance from Coff´s Harbour) plantations in different counties in the State of São Paulo, Brazil (Figure 1): two sites in São Miguel Arcanjo (23º51' S and 47°54' W; 725 m altitude); one site in Alambari (23°33' S and 47°53' W; 650 m altitude); one site in Angatuba (23°00' S and 48°52' W; 740 m altitude); and one site in Itatinga (23°06' S and 48°36' W; 700 m altitude). The ages of these plantations ranged between 6.5 and 7.0 years. The climate is predominantly of the Cfa type (humid mesothermal, no drought period, classification of Köppen). Some climate conditions and soil water balance for the different sites are shown in Table 1. To establish these stands, the soil was ripped in lines at 3 m intervals to a depth of 40 cm and *E. grandis* seedlings were planted at 2 m intervals in ripped lines. NPK fertilizer (260 kg ha^{-1}, 06-30-06) was applied at planting. Post-planting NPK fertilization occurred at ages three months (80 kg ha^{-1}, 20-00-20) and two years (300 kg ha^{-1}, 14-07-28).

At each site, three plots (20 × 30 m each) containing 100 plants were demarcated at random. The diameters at breast height (DBH) and heights of all trees were measured. The DBH data were then classified into four classes of frequency.

The soils in the sites of São Miguel Arcanjo were characterized as Typic Hapludox (Red Latosol), clayey (LVd1) and very clayey (LVd2); in Alambari as Typic Hapludox (Red-Yellow Latosol), loamy (LVAd); and in Itatinga and Angatuba as Typic Quartzipsamment (Quartzarenic Neosol; RQ1 and RQ2). Physical and chemical attributes of the 0 - 20 cm layer are shown in Tables 2 and 3. Ten single soil samples per plot were collected in a diagonal transect. These samples were

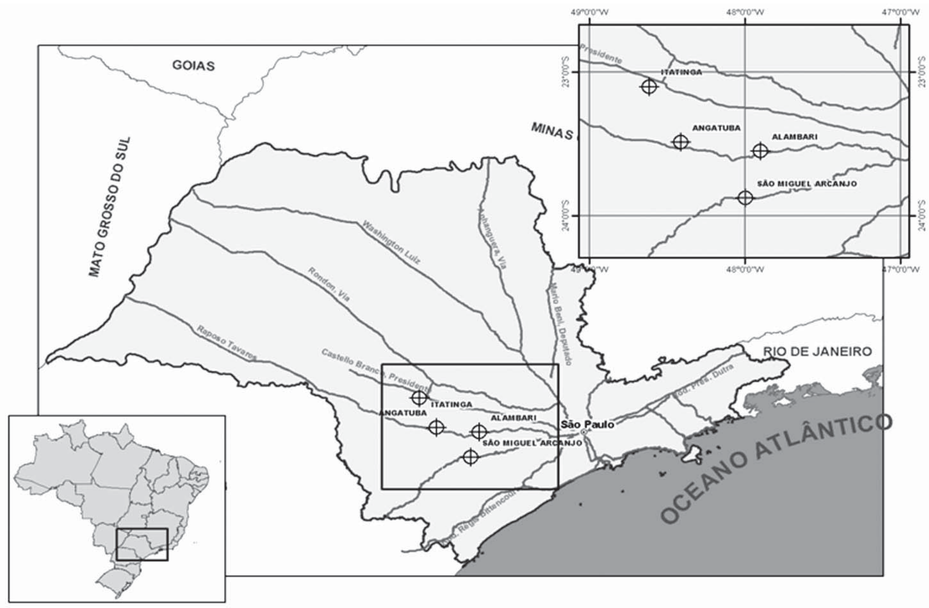

Figure 1- Location of municipalities in the State of São Paulo containing the experimental sites.

Table 1 - Soil water balance according to Thorntwaite & Mather (1955) at the experimental sites in different municipalities. Mean annual temperature (T), rainfall (PP), potential evapotranspiration (ETP), water excess (EXC) and deficit (DEF) are presented (period from 1990 to 2004). A soil storage capacity of 125 mm of available water was assumed.

Municipality	T	PP	ETP	EXC	DEF
	ºC	mm			
Angatuba and Itatinga	20	1492	968	528	3.9
Alambari	20	1486	1017	472	3.3
São Miguel Arcanjo	20	1472	1024	459	10.9

Table 2 - Physical attributes of soils (0 - 20 cm layer) in the *Eucalyptus grandis* stands.

Soil[1]	Sand	Silt	Clay	Bulk density	Total porosity	Available water - (0.01 - 0.15) MPa
	g kg^{-1}			kg m^{-3}	m^3 m^{-3}	
RQ1	934	26	40	1.50	0.43	0.04
RQ2	862	58	80	1.54	0.51	0.06
LVAd	716	96	188	1.53	0.46	0.10
LVAd1	465	96	439	1.16	0.74	0.09
LVAd2	240	129	631	0.90	0.58	0.14

[1] RQ1 and RQ2 = Typic Quartzipsamment; LVAd = Typic Hapludox, loamy; LVd1 = Typic Hapludox, clayey; and LVd2 = Typic Hapludox, very clayey

Table 3 - Chemical attributes of soils (0 - 20 cm layer) in the *Eucalyptus grandis* stands.

Soil	pH[1]	O.M.[2]	P-resin[3]	Exchangeable cations[3]			
				K^+	Ca^{2+}	Mg^{2+}	Al^{3+}
		g kg^{-3}	mg dm^{-3}	$mmol_c$ dm^{-3}			
RQ1	3.8	10.9	4.0	0.2	2.6	0.7	10.2
RQ2	3.8	15.9	8.2	0.3	3.5	0.9	16.5
LVAd	3.9	12.0	4.8	0.7	3.6	1.6	16.6
LVd1	3.7	38.4	5.1	0.5	3.9	2.2	28.6
LVd2	3.9	46.6	4.2	0.6	2.9	1.2	31.5

Extractors: [1] 0.01 mol L^{-1} $CaCl_2$ (soil to solution ratio 1:5); [2] potassium dichromate and sulfuric acid extraction; [3] ion exchange resin (Raij et al., 2001)

combined into compound samples, which were air-dried, homogenized, pounded to break up clods, and sifted (2 mm sieve). The evaluations included: pH in $CaCl_2$ 0.01 mol L^{-1}, organic C, extractable P and S-SO_4^{2-}, and exchangeable Ca, Mg, K and Al (Raij et al., 2001). The analysis of soil texture was performed according to Camargo et al. (1986). Five single samples per plot were collected to determine the soil water availability. Rings with a 50 mm diameter by 50 mm height were used, and samples were taken at 10 - 30 cm layer. After saturation with water, these samples were submitted to potentials of -0.01 and -1.5 MPa, using pressure values applied to porous-plate apparatuses (Klute, 1986). Once drainage stopped and when apparent hydraulic equilibrium was reached, the samples were weighed and then dried in an oven at ± 105°C for 24 hours, for bulk density determination (Blake & Hartge, 1986).

One medium-sized tree from each DBH class was felled per plot. Dendrometric evaluations were done for all felled trees: commercial (until a minimum diameter of 6 cm) and total stem height, and DBH. Twelve disks were cut from the stem with thickness of approximately 2.5 cm. Two disks were obtained from the tips (base and top), one disk at the height of DBH, and nine disks at every 10% of the tree's commercial height. Diameter measurements were obtained for each disk (with and without bark) and the basic density was determined by the hydrostatic balance method (ABTCP, 1974). The solid volume of each tree was calculated based on the information from the measurements made at every 10% of commercial height, using Smalian's formula:

$$V_t = \pi/8L\ [D_1^2 + D_n^2 + 2\ (D_2^2 + D_3^2 + \ldots D_{n-1}^2)]$$

where Vt is total volume; L is log length; and D is log diameter. The dry wood and bark masses were obtained by multiplying the basic densities obtained for the disks by the calculated volume.

The stems of each tree were individually chopped in an industrial tree chopper. The chips thus obtained were classified into thicknesses ranging from 2 to 5 mm and lengths varying between 2.5 and 3.0 cm and the compound samples per plot were then submitted to pulping. The pulping conditions were established by fixing the kappa number at 17 ± 0.5, at a cooking temperature of 165°C. A temperature ramp time of 90 minutes was adopted, and the maximum temperature was reached in 60 minutes. Cooking liquor sulfidity was 24%, and the alkali load was variable and adjusted as needed to reach the desired Kappa number.

Air-dried compound samples of chips from each tree were separated and ground in a Willey brand mill. The resulting sawdust was classified through sieves to yield a sample in the fraction between 40 and 60 meshes. Samples of each tree were analyzed to: a) total extractives and b) total lignin (Gomide & Demuner, 1986). The holocellulose content was obtained by the equation: 100 – (Total extractives + Lignin %).

The data were submitted to descriptive statistical analysis, analysis of variance (ANOVA), and regression analysis. The regression equations were selected based on the adjusted coefficient of determination (R^2), residual standard error (s) values, and on the graphical analysis of residues. The statistical programs used in the analyses were SAS (1996) and SIGMAPLOT (2002).

RESULTS AND DISCUSSION

The tree growth was directly associated with the soil type and textural classes (Figure 2). The lowest growth was recorded in the Quartzipsamment, while the highest was recorded in the very-clayey Hapludox. Soil texture has been reported as the most important attribute to explain the soil's productive potential (Braga et al., 1995).

Exponential relations were found between the mean annual increment (MAI) of wood (volume and mass) and clay content (Figure 3). Productivity increased markedly up to clay values between 350 and 400 g kg^{-1}, and then tended to become stabilized. Significant correlations between forest productivity and soil clay content were found by several researchers (Bowersox & Ward, 1972; Braga et al., 1995). The positive influence of clay content on productivity is mainly due to increase of available water content in the soil (Figure 4). Lopes (1977) also found higher available water with increasing clay content in soils from Brazilian savanna region, reaching maximum values at clay contents between 350 and 600 g kg^{-1}.

High water uptake has been reported as an attribute of fast-growing *Eucalyptus* species (Lima &

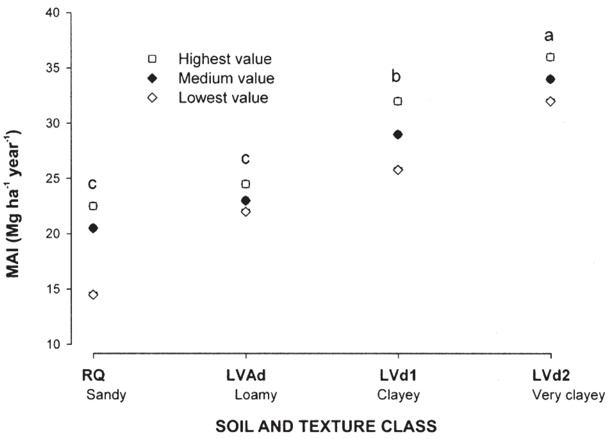

Figure 2 - Mean annual increment (MAI) of wood mass related to different soil type and textural classes. Means followed by same letter are not different by Tukey's test (P = 0.05).

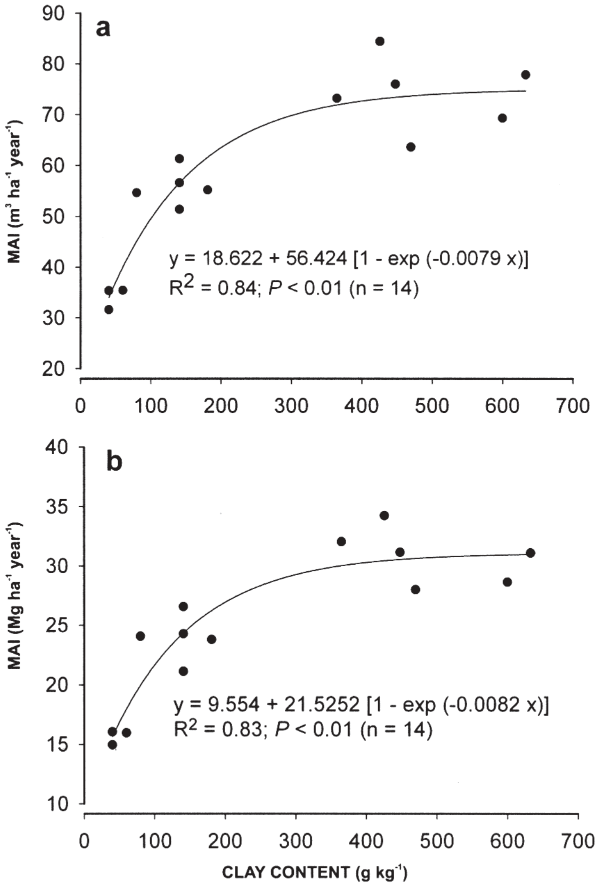

Figure 3 - Relations between increases in mean annual increment (MAI) in solid wood volume (a) and wood mass (b), and clay content (0 - 20 cm layer).

Zakia, 1998; Lima et al., 2003). Because of this, the soil's water regime is one of the most important factors that determine productive capacity (Melo et al., 1995; Leite, 1996). The smallest productivity increases related to clay content were observed in the sandy- and loamy-textured soils, which showed pronounced internal drainage and low water holding capacity, thus being more susceptible to water deficit (Gonçalves, 2002). No significant relationship was verified between wood mass (MAI) and soil P, Ca and K contents. The best correlations were found for organic matter, exchangeable Al, and effective CEC, but it normally presents high correlation with soil clay contents (Schimel & Parton, 1986).

The mean basic wood density varied little (0.44 to 0.45 g cm^{-3}) between soil classes (Figure 5). Site quality did not influence the basic wood density of *Eucalyptus grandis* (Retief et al., 1997), confirming the results found in this paper. On the other hand, an exponential relationship was found between basic wood density and tree volume (Figure 6). Hence, higher tree growth positively influence basic density, regardless of soil type, which is in according to another report (Zobel & Buijtenen, 1989), who found increased wood density for eucalypt while tree growth rate increases. The increase in wood density is due to greater fiber length, with thicker cell walls (Ferreira, 1972; Shimoyama & Barrichelo, 1991), which could be a consequence of higher water and nutrient uptake (Florsheim et al., 2000).

The mean contents of holocellulose, extractives and total lignin showed different behaviors depending on soil type and tree DBH (Figure 7). Holocellulose and total lignin contents were related to soil type, and contents of extractives did not vary between soil types and DBH values. The holocellulose content increased about 4% between the sandy-textured and the very clayey soil, while total lignin content decreased about 3%. Considering that holocellulose and total lignin in association with empty spaces determine basic wood density, it is deduced that these opposite range of wood contents justify the lack of range to mean basic wood density concerning to soil types.

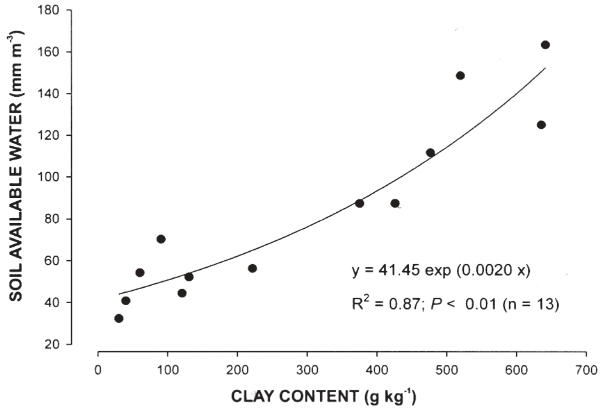

Figure 4 - Relation between soil available water (field capacity, 0.01 MPa, minus permanent wilting point, 1.5 MPa) and clay content (0-20 cm layer).

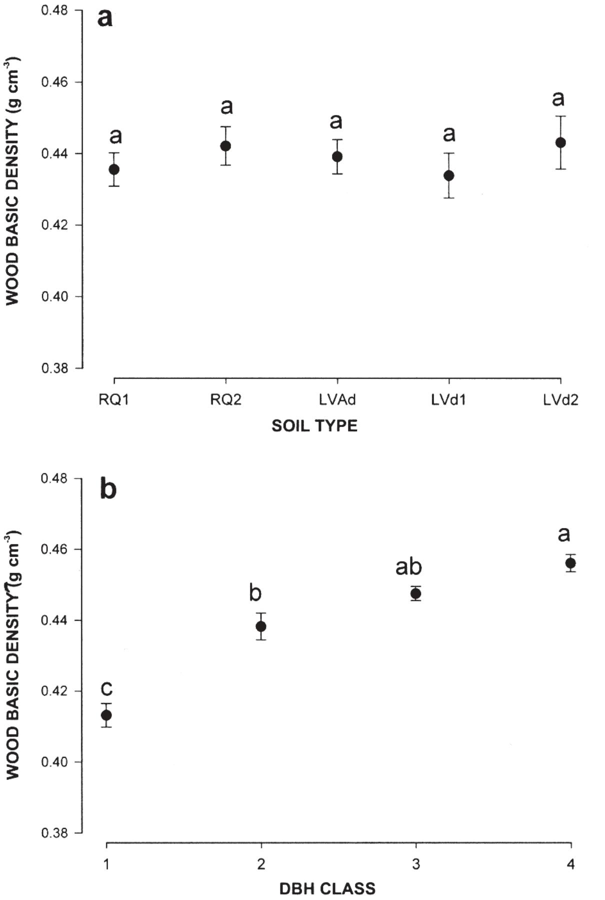

Figure 5 - Mean values and standard deviation for wood basic density related to soil type (a) and to diameter at breast height (DBH) frequency class (b). Means followed by same letter are not different by Tukey's test ($P = 0.05$).

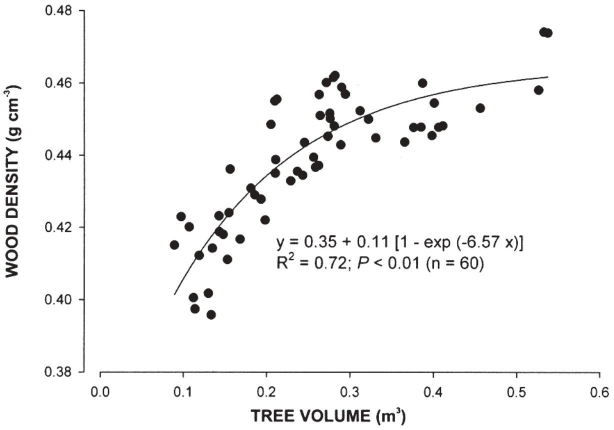

Figure 6 - Relation between wood basic density and tree volume.

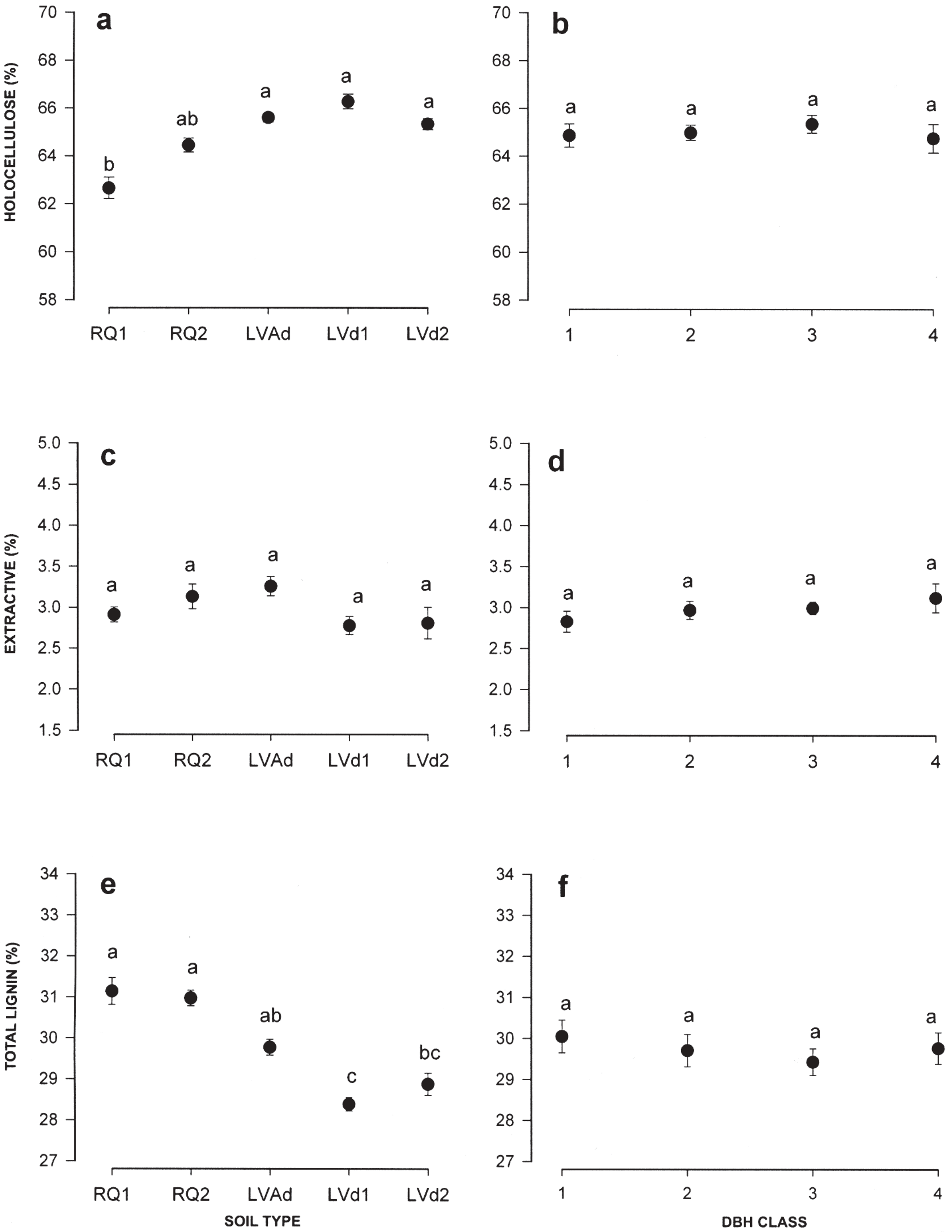

Figure 7 - Mean values and standard deviation for holocellulose (a and b), total extractives (c and d), and total lignin (e and f) contents, respectively, according to soil type and tree DBH. Means followed by same letter are not different by Tukey's test (*P* = 0.05).

As found for wood productivity, the holocellulose and total lignin contents were exponentially related to soil clay content (Figure 8). The holocellulose content increased while the lignin content decreased as the clay content increased, which is directly related to soil water availability. Water availability regulates the production of photoassimilates by means of the degree of stomatal opening (Larcher, 1975; Kozlowski, 1982). Therefore, as higher is soil water availability as higher are cambium metabolism and photoassimilate yield (Kriedemann & Cromer, 1996), such as holocellulose. The wood formation increases with cambium activity, since it requires higher synthesis of xylem vessels and fibers (Ridoutt & Sands, 1994), a process strongly in-

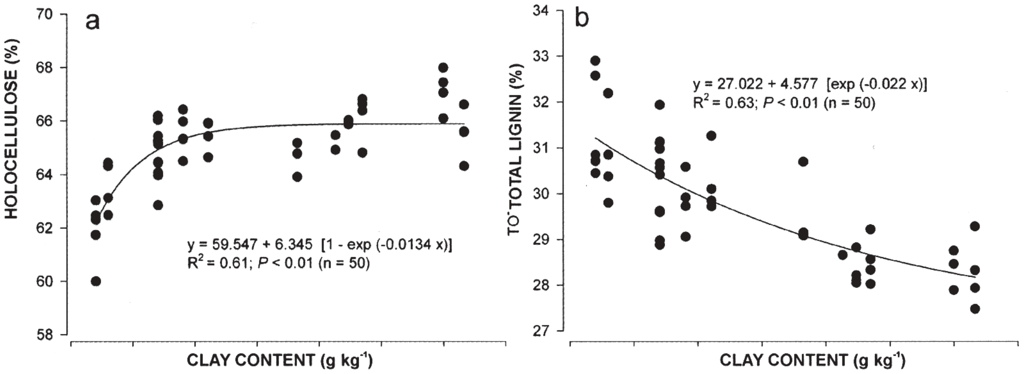

Figure 8 - Relation between holocellulose (a), total lignin (b) and clay content (0-20 cm layer).

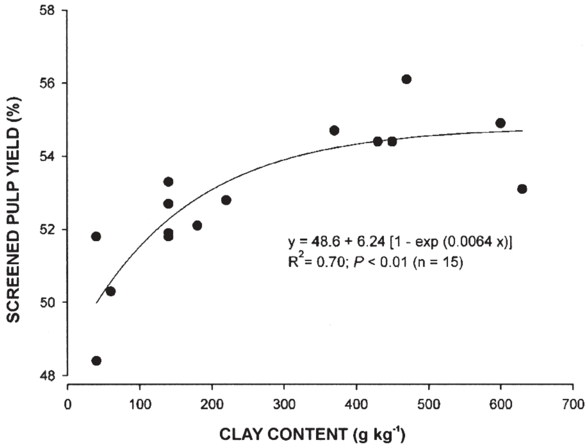

Figure 9 - Relation between depurated cellulose yield and soil clay content (0-20 cm layer).

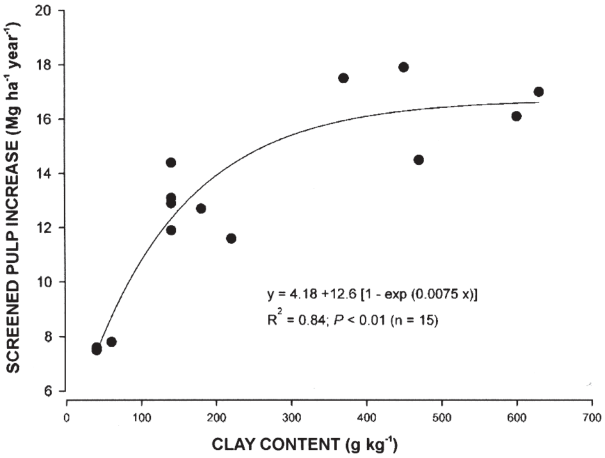

Figure 10 - Relation between screened pulp increase and clay content (0 - 20 cm layer).

fluenced by water availability in eucalypt trees (Zahner, 1968). Lignin is a key component for water transport in vascular tissue, then important for plant adaptation to water stress (Kriedemann & Cromer, 1996). So, under water constraints, there should be higher lignin production, as in the present study, either to increase tree water conductivity (Kriedemann & Cromer, 1996) and to reinforce tree structure, protecting it from the penetration of external agents (Davin & Lewis, 2000), such as pests and diseases.

Screened pulp yield was exponentially related to soil clay content (Figure 9). Screened pulp yield increased up to clay contents between 350 and 400 g kg^{-1}, similar to results found for MAI and wood mass. Retief et al. (1997) found an exponential relation between screened pulp yield and site index, a variable closely related to soil texture.

The increase in screened pulp per hectare was also exponentially related to clay content (Figure 10). Based on the fitted equation, the clayey- and very clayey-textured soils (mean clay content of 470 g kg^{-1}) yielded on average 10% more screened pulp per hectare than loamy soils (mean clay content of 250 g kg^{-1}), and these 55% more than sandy-textured soils (mean clay content of 8 g kg^{-1}). This pulp yield increase can be explained by the increase in holocellulose content and decrease in lignin content, which were also correlated with the clay content. Otherwise, screened pulp yield was not correlated with basic wood density and may have been positively influenced by the reduction in lignin content (Barrichelo & Brito, 1983) as the soil clay content increased.

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