THE VARIATION OF CHEMICAL COMPOSITION AND PULPING YIELD WITH AGE AND GROWTH FACTORS IN YOUNG *EUCALYPTUS GLOBULUS*

Isabel Miranda
Researcher

and

Helena Pereira†
Professor

Centro de Estudos Florestais
Instituto Superior de Agronomia
Univerdade Técnica de Lisboa
1349-017 Lisboa
Portugal

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ABSTRACT

The wood quality of 2-, 3-, and 6-year old *Eucalyptus globulus* trees was assessed in relation to chemical composition and pulping for two growth conditions: a control (C) and optimized growth (IL) through a weekly nutrient supply and irrigation.

The wood chemical composition did not show statistically significant differences between C and IL trees. With age an increase was found for lignin and extractives, especially ethanol and water-solubles.

The overall average pulp yield was 56.5% at a Kappa number of 15. No differences in pulp yield or delignification degree could be associated with fertilization and irrigation or with tree age. In these conditions, intensively grown trees and shorter rotations may be used for pulping without loss of raw-material quality.

Keywords: *Eucalyptus globulus*, fertilization, irrigation, chemical composition, pulp yield.

INTRODUCTION

Eucalypts are nowadays planted worldwide in intensive short-rotation systems for pulpwood production. Reliable global estimates of areas of planted eucalypts are difficult to obtain, but published reports suggest that there are at least 12 million ha (Turnbull 1999). *Eucalyptus globulus* was the first species to be used in large-scale plantations for the pulpwood industry, especially in southern Europe (Portugal and Spain), where the species now covers approximately 1 million ha.

Eucalyptus globulus combines fast growth under appropriate conditions, with good tree form and excellent wood quality for pulp production. The usual management is based on a coppice system, in 7- to 13-year rotation cycles, with a planting density of approximately 1100 plants ha^{-1} and fertilization at planting. Growth rates may reach an average 20 m^3ha^{-1} $year^{-1}$ in good site conditions, but are strongly influenced by soil water and mineral nutrient availability (Cromer and Williams 1982; Pereira et al. 1989).

In intensive plantations, maximizing production by appropriate genetic selection and by use of growth enhancement measures, e.g., fertilization, is usually the aim, eventually accompanied by a decrease of rotation age, in case there are no detrimental effects on wood quality.

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† Member of SWST.

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Cultural practices that increase growth rate, e.g., fertilization or irrigation, are thought to influence the raw-material quality of such plantations, but research has been limited and results for hardwoods are often not conclusive.

The raw-material quality of fast-growing plantations in the early stages of growth (1–4 years old) has been studied in species such as *Populus, Salix,* and *Eucalyptus* (Vital et al. 1981; Bamber et al. 1982; Phelps et al. 1982; Bhat and Bhat 1984; Blankenhorn et al. 1988). In the case of eucalypts, younger trees are preferred for pulpwood (Higgins 1984), and reports have been given on the pulping suitability of very young (1–6 years old) plantation-grown *E. globulus*, where the use of fertilizers had no detrimental effect on pulping and pulp properties (Cromer and Hansen 1972; Farrington et al. 1977). In *E. globulus* with an age range of 2–6 years, pulp yield increased and alkali consumption decreased with increasing age and fertilization was not detrimental to pulp strength properties (Ferrari 1983). In *E. grandis* aged 5 years, pulp yield increased and Kappa number decreased with the use of the fertilizers (Cromer et al. 1998).

This paper reports results on the wood chemical composition and pulping yield of 2-, 3-, and 6-year-old *Eucalyptus globulus* trees, obtained from an experimental trial where growth was increased by nutrient and water supply.

MATERIALS AND METHODS

The raw material was obtained from *Eucalyptus globulus* Labill. trees grown in an experimental plantation in Óbidos, Portugal (32° 02′N; 09°15′W), about 10 km from the Atlantic Ocean. The climate is of the Mediterranean type tempered by oceanic influence with a mean annual temperature of 15.2°C and a rainfall of 607 mm. The soils are of low fertility, mostly sandy, and classified as spodosols.

The plantation was established with plants from a commercial seed source, at 3- X 3-m^2 spacing, and was designed to study the growth response of *Eucalyptus globulus* in relation to different water and nutrient environments. Dolomite limestone was applied before planting, and a commercial fertilizer was supplied to each seedling at planting. The experimental design included a control and three treatments with different irrigation and fertilization, with two replications, as described in detail by Pereira et al. (1989).

The samples studied here were obtained from trees with different growth rates: C— control, without treatment; IL— an optimized growth treatment with daily irrigation and weekly addition of liquid fertilizer, adapted to fulfill plant growth needs.

The IL treatment had a strong effect on eucalypt growth: the average stem biomass at 6 years of age was calculated as 120.5 kg and 65.8 kg per tree, respectively in IL and C treatments. The biomass per tree in the IL treatment was 2.4, 2.5, and 1.7 times larger than in the control (C) at 1, 2, and 6 years after planting, respectively (Fabião et al. 1995).

Five trees in each of the two plots of each treatment were harvested at 2, 3, and 6 years fter planting. A disc was taken at b h (breast height) and the wood analyzed individually for each tree.

The chemical composition was determined in 40-60-mesh woodmeal following the methods standardized by the Technical Association of Pulp and Paper Industry (TAPPI 1994–1995). Determination of ash, klason lignin, and acid soluble lignin was made according to Tappi T 221 om-93, Tappi T 249 pm-75, and Tappi T um-250, respectively. Total extractives were determined in a Soxhlet apparatus using a sequence of dichloromethane, ethanol, and water. The polysaccharides were calculated based on glucose and xylose after total hydrolysis and separation and quantification by high pressure liquid chromatography (HPLC).

Kraft pulping was performed on small wood chips ($2 \times 0.2 \times 0.2$ cm^3) in 100-ml rotating stainless steel reaction vessels (with charges of 10 g oven-dry wood), immersed in a temperature-controlled oil bath. The conditions were as follows: liquor-to-wood ratio 4.5:1, 15% active alkali, 30% sulphidity, pulping temperature 170°C, pulping time 2 h. Pulp yields were calculated based on the oven-dry weight of wood chips charged to the reactor, and the Kappa number was determined. The analysis was made individually for each tree.

The effect of age and treatment on the several parameters was analyzed with the following ANOVA model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{(ij)k} \qquad (1)$$

where Y_{ijk} is the individual tree measurement taken on the jth age on kth replication in ith treatments; μ is the overall mean; α_i is the effect of the ith treatments; β_j is the effect of the jth age; $(\alpha\beta)_{ij}$ is the effect of interaction of jth age and ith treatments; and $\epsilon_{(ij)k}$ is the experimental error associated to observation Y_{ijk}. The analysis of variance was made using the Scientific Statistical software SigmaStat© for Windows Version 2.0, from Jandel Corporation.

RESULTS AND DISCUSSION

Chemical composition

The wood chemical composition for the *Eucalyptus globulus* trees in the IL and C treatments with 2, 3, and 6 years is given in Table 1.

The chemical composition was similar in the two treatments, and irrigation and fertilization did not show a clear effect. On average, irrigated and fertilized trees (IL) had a somewhat higher lignin content than control trees (C), e.g. 28.3 and 27.3%, respectively, for the 6-year-old wood. Extractives were also higher in the 3- and 6-year-old IL trees, e.g. 5.8% and 4.2% for 6-year-old IL and C trees, respectively. However, an analysis of variance showed that there was not a statistically significant difference between the two treatments in factors relating to chemical composition.

Previous results (Cromer and Hansen 1972) on 2-, 4-, and 6-year-old *Eucalyptus globulus* showed that the lignin content was similar between fertilized trees (20.3%) and control trees (20.1%); but in *Eucalyptus grandis* a small increase in klason lignin content with addition of fertilizer (25.6%) was found in relation to control trees (24.4%) (Cromer et al. 1998).

Between-tree variation was found for most chemical components. For instance, lignin for the 10 trees of one age and treatment may vary from 22.6% to 32.8% (IL, 6 years) and the

TABLE 1. *Chemical composition of* Eucalyptus globulus *wood determined on breast height discs of trees aged 2, 3, and 6 years, with different growth (C and IL). Average of 10 trees per treatment, with the standard deviation in parentheses.*

	2 years		3 years		6 years	
	C	IL	C	IL	C	IL
Ash	0.8 (0.3)	0.8 (0.2)	1.7 (0.9)	2.1 (0.7)	0.6 (0.2)	0.6 (1.2)
Extractives						
dichoromethane	0.4 (0.2)	0.5 (0.2)	0.8 (0.2)	1.0 (0.5)	0.5 (0.2)	0.5 (0.3)
ethanol	1.8 (0.2)	1.5 (0.3)	3.1 (1.4)	4.2 (1.6)	1.8 (0.5)	2.5 (1.9)
water	2.1 (0.7)	1.7 (0.4)	4.0 (1.0)	3.9 (1.0)	1.9 (0.5)	2.8 (1.5)
total	4.2 (0.9)	3.6 (0.4)	7.9 (2.9)	9.1 (2.2)	4.2 (0.9)	5.8 (2.0)
Lignin						
soluble	4.6 (1.4)	4.6 (2.3)	2.9 (0.6)	3.0 (0.6)	2.2 (0.9)	1.5 (0.3)
klason	22.3 (2.4)	23.3 (2.4)	25.7 (3.7)	27.8 (4.0)	25.1 (3.0)	26.8 (4.2)
total	26.9 (2.3)	27.9 (2.3)	28.6 (3.8)	30.8 (4.3)	27.3 (3.1)	28.3 (4.0)
Carbohydrates						
glucose	50.0 (1.7)	49.0 (2.0)	40.2 (2.3)	40.1 (1.7)	43.8 (2.2)	41.8 (2.5)
xylan	18.6 (1.3)	17.7 (1.5)	15.4 (2.1)	18.0 (1.8)	19.8 (1.9)	18.9 (3.0)
total	68.6 (1.0)	66.7 (2.1)	55.6 (3.3)	58.1 (3.2)	63.6 (2.7)	60.7 (5.6)

coefficients of variation for the mean lignin content ranged for all cases between 11.4% and 14.1%. The variability in extractives was higher, and in most cases the coefficients of variation were in the range of 20–50% of the mean.

Pereira (1988), who studied the variability in chemical composition of *E. globulus* at harvest age, found a large variability in chemical composition in relation to cellulose but only a moderate variability in relation to lignin: for instance, tree cellulose content of individual trees varied from a lowest value of 46.6% to a highest value of 60.7%, and the lignin contents of individual trees from 21.7% to 26.6%. Wallis et al. (1996) in 10-year-old *E. globulus* also found moderate variability between trees with lignin klason content of individual trees from 19.2% to 23.2%.

Recent reports on provenance and site effects on chemical composition of *Eucalyptus globulus* at 9 years of age, showed that the within-provenance variation was small for lignin, glucan, and xylan and moderate for extractives for which the coefficient of variation of the mean was approximately 25%. The differences in chemical composition between provenances were not statistically significant for all components except for extractives (Miranda and Pereira 2001).

No correlation could be established between chemical composition and enhancement of growth. These results lead to the conclusion that an enhancement of growth by manipulation of the water and nutrients available to the plants will not be detrimental to the wood chemical quality. It is also of interest to note that the between-tree variability did not increase in the IL treatment in relation to the control.

A comparison between the three tree ages indicates a small increase of lignin content with age and a decrease of polysaccharides but without statistical significance, e.g., lignin was 27.8% in 6-year-old and 27.9% in 2-year-old IL wood. Extractives increased with age, mostly as a result of the presence of more ethanol and water-soluble material, which amounted for more than 89% of the total extractives. The main difference in chemical composition was found for the 3-year-old trees, which showed a higher amount of extractives and lignin.

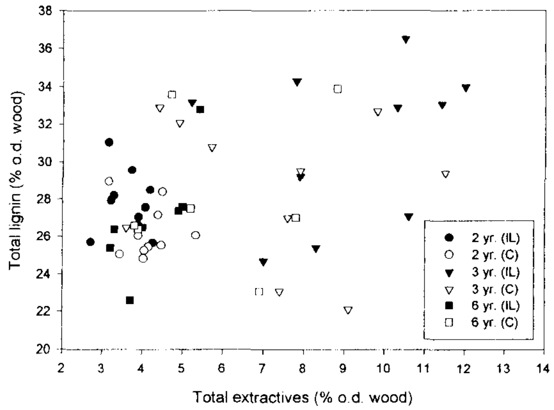

FIG 1. Scatter plot of total lignin and extractives content for 2-, 3-, and 6-year-old *Eucalyptus globulus* trees with different growth (C and IL).

However, the results do not differ substantially from the chemical composition of eucalypt wood at the normal harvest age for the pulping industry of 10–13 years (Pereira 1988): ash 0.4%, total extractives 4.9%, total lignin 23.1%, cellulose 54.0%, and pentosans 18.9%. Miranda and Pereira (2001), using 4 provenances of *E. globulus* at 9 years, also found similar values: 3.7% extractives, 26.1% lignin, 49.8% glucan, and 14.4% xylan.

No relationship between lignin and extractives content was obtained, as seen on the scatter plot of Fig. 1 where the tree individual parameters were plotted.

Pulping

The kraft pulping characteristics for the IL and C trees aged 2, 3, and 6 years are given in Table 2. The overall average pulp yield was 56.5% at a Kappa number of 15. The pulp yields obtained are in general superior to the range reported for *E. globulus* wood at a similar age. A pulp yield of 49% at K 17 was reported by Cromer and Hansen (1972) for 2-year-old *E. globulus* trees. Values between 48% and 54.4% at K15 for *E. globulus* at 6

TABLE 2. *Pulp yield and Kappa no. of* Eucalyptus globulus *wood determined on breast height discs of trees aged 2, 3, and 6 years, with different growth (C and IL). Average of 10 trees per treatment, with the standard devation in parentheses.*

	2 years		3 years		6 years	
	IL	C	IL	C	IL	C
Pulp yield (%)	57.4 (1.9)	56.2 (1.1)	55.8 (2.9)	55.4 (1.3)	57.2 (1.8)	57.1 (1.9)
Kappa number	14.2 (0.5)	15.8 (0.7)	13.6 (0.5)	13.9 (0.5)	15.5 (0.6)	16.6 (0.6)

and 10 years, respectively, and 46.8% and 54.0% for *E. nitens* at 7 years were reported by Wallis et al. (1996). Farrington et al. (1977), in a study based on *E. globulus* at ages 2, 4, and 6 years from a fertilizer experiment, found that pulp yield increased with age, with values between 50% at K18 and 56% at K20 for 2 and 6 years, respectively.

No differences in pulp yield or delignification degree could be associated with fertilized and irrigated and control trees. The pulp yield was 56.2% for the control and 56.8% for the fertilized and irrigated trees, and the Kappa numbers were practically the same. Cromer et al. (1998), who examined the wood properties and kraft pulp yield of *E. grandis* from fertilizer trials at 5 years, found that the pulp yield increased slightly from 48.4% to 51.1% (at K20) for unfertilized and fertilized trees, respectively.

The results did not show a tree age effect, with the exception of the 3-year-old trees, which showed a somewhat smaller yield in accordance with the higher content of extractives. However, on an individual tree basis, no clear correlation could be found between content of lignin and extractives and pulp yield (Fig. 2).

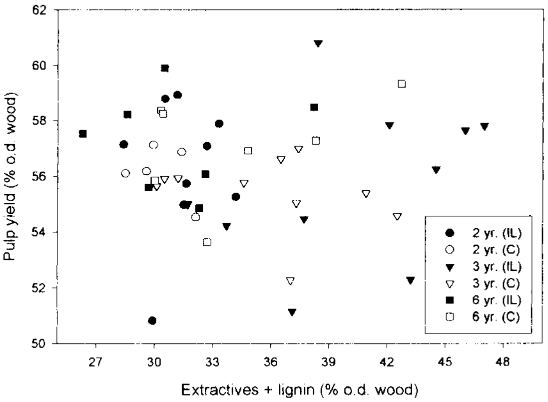

FIG 2. Scatter plot of lignin and extractives content and pulp yield for 2-, 3-, and 6-year-old *Eucalyptus globulus* trees with different growth (C and IL).

It is interesting to note the small between-tree variability of pulp yield and Kappa number, which shows coefficients of variation of the mean below 5%.

CONCLUSIONS

The analysis of plantation-grown *E. globulus* trees at age 2, 3, and 6 years showed that an enhancement of growth may be obtained by use of fertilization and irrigation without significant impact in the wood chemical composition and pulp yield. In these conditions, intensively grown trees and shorter rotations may be used for pulping without loss of raw-material quality.

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