WOOD AND PULPING PROPERTIES OF *EUCALYPTUS UROPHYLLA* AND ITS HYBRID GROWN BY SILVOPASTORAL AND CONVENTIONAL FOREST PRODUCTION MODELS

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This study compares the wood and the pulping characteristics of *Eucalyptus urophylla* and the hybrid *Eucalyptus urophylla x Eucalyptus grandis* grown by two forest production models: the conventional system (3 × 3 m) and the silvopastoral one (9 × 2 m), in Ribas do Rio Pardo, MS, Brazil. The specific objectives were to compare the dendrometric parameters, the physical and chemical properties and the kraft pulping of the wood of the trees grown by both forest production models. 20 trees (2 species × 2 forest production models × 5 trees) from areas with similar soil characteristics (quartz sand soils), with an approximate age of 4.5 years, were collected. The production model had a greater influence on the wood's chemical composition, compared to the species. The silvopastoral system (9 × 2 m) significantly decreased the average basic density of the tree, increased the percentage of bark in the tree volume, increased the solubility of the wood in 1% NaOH, decreased the holocellulose content in the wood and increased the ash content. The chemical analyses showed better properties for kraft pulping of the *E. urophylla* wood from the conventional production system. Both the silvopastoral production (9 × 2 m) and the conventional (3 × 3 m) systems exhibited positive and expected outcomes in relation to basic density and chemical analysis conducted on the wood.

Keywords: spacing, silvopastoral system, dendrometric parameters, physical and chemical properties of wood, kraft pulping

INTRODUCTION

In Brazil, the genus *Eucalyptus ssp*. is one of the most commonly planted species; its phenological characteristics and ability to adapt to different environmental conditions, resistance to drought and disease, as well as rapid growth, have allowed its wood to be used for a variety of industrial applications.[1-2]

At present, with an active forestry market and a rising demand for wood across multiple segments, in some regions in Brazil, such as Mato Grosso do Sul, traditionally known for their significant meat and dairy production, investments are already made in silvopastoral management as an opportunity to diversify property use.

Silvopastoral systems are based on natural, planned or converted cattle pastures. Livestock is rotated in an area at the same time and certain tree species are chosen to promote better use of natural resources to increase productivity per unit area. In these systems, interactions of all types and magnitudes occur, with the goal of obtaining greater productive diversity on rural property.[3-4]

A fundamental requirement for the success of sustainable silvopastoral systems is the right choice of species to form the system, and the deciding factors include the ultimate goal of land use, soil and climatic conditions in the region, the spatial distribution of trees and especially, market conditions and the quality of the products being grown.

Botelho[5] and Macedo *et al*.[6] commented that few studies have focused on silvopastoral systems to evaluate *Eucalyptus spp.* under varied planting conditions; most of the studies conducted have discussed a spacing of 2-3 m between plants and between rows in simplified arrangements. In addition, most projects addressing spacing, density, and wood quality have neglected to consider alternative methods of monoculture cultivation, especially with regard to implementing agroforestry and silvopastoral systems. These factors must be evaluated initially as the preliminary growth dynamics of the clones are likely to affect the management and the quality of the final product.

To generate more data on the development and quality of these plantations in the region, two most commonly planted clones of *Eucalyptus* were selected. We conducted a comparative study of the dendrometric parameters, the physical and chemical properties, as well as the kraft pulping abilities, comparing a conventional production system (3 × 3 m) with the silvopastoral production system (9 × 2 m).

EXPERIMENTAL

Characteristics of the experimental area

The experimental area belongs to Mutum Group (Mutum Reflorestamento), on the Boa Aguada Farm, in Ribas do Rio Pardo, which is located in the southeast region of Mato Grosso do Sul. The geographic coordinates of the site are 20°26'31"S and 53°16'54"W, and it is located at an altitude of 470 m. The predominant climate in the region is, according to Köppen Cwa classification, semi-humid hot tropical, and is marked by rains in summer and dry periods during the winter. The annual temperature is approximately 25 °C, with a monthly average of 18 °C in the coldest season and 29.0 °C in the hottest season. Average annual precipitation ranges from 1,200 mm to 1,500 mm per year, concentrated in the period between November and early March.[7]

Characteristics of the material

The material used in this study was collected in areas with the same soil characteristics (quartz sand soils). Trees from a clone of *Eucalyptus urophylla* and trees from a clone of the hybrid *Eucalyptus urophylla x Eucalyptus grandis* became the purview of this study. The trees were approximately 4.5 years old and were planted by two forest production models: conventional 3 × 3 m and silvopastoral 9 × 2 m. In the area with the 9 × 2 m forest production model, the process began with the production of hay between the rows, and subsequent formation of pasture with the introduction of livestock in the second year. This contrasted with the 3 × 3 m forest production model, which was only used for timber production.

Tree sampling

A number of 20 trees were collected (2 species × 2 forest production models × 5 trees). The total height, commercial height and diameter at breast height (over bark) of the trees that were felled were measured. Then, a 5-cm-thick disk was cut from the base and at 25%, 50%, 75% and 100% of the commercial height, considering a minimum diameter of 8 cm over bark. From these disks, the dendrometric parameters were determined according to Smalian's formula,[8] basic wood density according to Foelkel *et al.*,[9] the chemical composition of wood according to TAPPI,[10] and kraft delignification.

Chemical composition of wood

With withdrawn wedges of 90° angle, the discs (collected at the base, at 25, 50, 75 and 100% of the commercial height of the trees, as mentioned before) were reduced to toothpicks, and then ground to sawdust in a Wiley mill. After this step, the resulting sawdust was classified to obtain the 40:60 mesh fraction. The following analyses were performed on each tree: solubility in 1% NaOH (TAPPI T 4 wd-75),[10] Klason lignin (*i.e.* lignin insoluble in sulphuric acid; TAPPI T 249 cm-85),[10] holocellulose (delignification with sodium chlorite) and ash (TAPPI T 211 om-93).[10]

Kraft delignification of wood and pulp analysis

The kraft delignification was performed in a Regmed rotary digester with a 20 l capacity. Kraft delignification conditions were as follows: dry wood base active alkali, Na_2O = 18%, liquor sulfidity = 25%, maximum temperature = 170 °C, time to maximum temperature = 90 min, and time at maximum temperature = 30 min. After kraft delignification and pulp washing, the screened yield and specific wood consumption were determined. The Kappa number test was performed on samples of purified pulp, according to TAPPI standard T 236 om-85.[10]

Statistical analysis

Exploratory analysis of the data obtained for both wood properties and kraft pulp quality recommended the adoption of parametric analysis methods (ANOVA) with treatments in a factorial design, taking into account the forest production model, the type of species and the application of the Tukey test, with a 5% significance level for multiple comparisons.

RESULTS AND DISCUSSION

Effect of forest production models on dendrometric parameters for *E. urophylla* and *E. grandis x E. urophylla* trees

As can be seen in Table 1, the analysis of the variation in tree volume (over bark) did not show any significant differences between the forest production models and among species.

The hybrid *E. urophylla x E. grandis* trees tended to have slightly higher growth than the *E. urophylla* trees, mainly in the conventional production system (3 × 3 m). These results have been shown to be directly linked to the fact that the *E. urophylla x E. grandis* hybrids possessed good characteristics in terms of adaptability to different forest sites and an increased productive capacity.[11-12] Regarding the influence of the forest production model, we can see that there were no significant differences in the volume of wood for both forest production models.

The assessment of the bark percentage in the tree volume by the variance analysis highlighted (Table 1) significant differences at the 1% level related to the forest production models. An increase of approximately 13% in the bark percentage was seen in the silvopastoral system over the conventional system.

This proportional increase in the amount of bark associated with the silvopastoral system, mainly for the hybrid, is believed to be related to the increased availability of light that the production model provides, allowing greater development of the peridermal plant tissue. The bark percentage is crucial for understanding tree behaviour, and it greatly influences the transportation of wood. Oliveira *et al.*[13] stated that from the forestry and industrial points of view, the bark percentage between species reveals external variations in shape and texture, and may permit overestimation in analysing stems in forest plantations.

Effect of forest production models on physical and chemical properties of wood from *E. urophylla* and *E. grandis x E. urophylla*

One of the main physical properties of wood is basic density, which is a strong universal index for evaluating wood quality, and is of fundamental importance to pulping. This also influences economic aspects, specific wood consumption, variables in the pulping process and the characteristics of cellulose pulp.[14-16]

The analysis of variance showed significant differences related to the production models, the interaction between species and factors (Table 1). The average basic density of the trees in the conventional system was higher by approximately 6.5% when compared to the silvopastoral system. Therefore, the average basic density tended to decrease with wider spacing. This difference in basic density is believed to be related to the volumetric growth of the species.

By comparing wood volume *vs.* basic density (Table 1), the study observes a proportional relation wherein the larger volume of wood presents the lowest densities and *vice versa.* Trugilho *et al.*[17] reported that higher density woods were related to an increased thickness of the cell wall, decreasing the volume and increasing the length of the fibres. For the overall average of basic density, looking only at the species, *E. urophylla* wood was superior with 1% significance when compared to the *E. urophylla x E. grandis* hybrid.

These results clearly demonstrate the objective of the crossing between *E. urophylla x E. grandis*, which was an increase in wood volume associated with the decrease in average basic density, which can be explained by the presence of *E. grandis* in this material, a species that is characterized by a basic density generally inferior to *E. urophylla* (approximately 0.420 g/cm³), according to Milagres.[18]

For the solubility of wood in 1% NaOH (Table 2), a significant effect was observed at the 1% level only for the production model. The increase in spacing represented by the silvopastoral system increased alkaline solubilisation by 13.2%, compared with the conventional system. The general averages had no significant variation.

As greater solubility in NaOH indicates a greater ease in removing hemicelluloses in alkaline solutions, this study concluded that wider spacing provides greater wood solubility, impacting the pulp and paper production process. Ferreira *et al.*[19] reported that maximum preservation of hemicelluloses is essential to increase the process yield.

Another essential analysis that is of representative value in the pulping process is the study of the fundamental components of wood, such as lignin and holocellulose. The analysis of the general variance did not show significant differences for the lignin percent in the wood (Table 2); however, the results show signs of a slightly elevated level of lignin with increased spacing.

An increasing lignin level for both species with spacing are in line with the results found by Garlett,[20] who studied the influence of five different spacings on wood quality and also found higher lignin levels for wider spacing.

Comparing the general average between basic density and lignin content (Tables 1 and 2), we can see that the wood with the higher basic density had a lower lignin content. Trugilho *et al.*[17] also observed a negative correlation between lignin and basic density in a study on 24-month-old *Eucalyptus saligna*; these authors related the young age of the samples that did not elevate the lignin content to stability.

In this analysis, no great difference among treatments was seen, only tendencies at the percentage levels cited above, thereby demonstrating that using these types of wood in the industry is viable.

As per the chemically-processed pulp production, lignin is classified as a harmful constituent. High levels in the wood require more active alkali in the process of chip impregnation during cooking and bleaching operations, impairing operations.[15-16,21-22]

Holocellulose represents the total polysaccharides present in the wood and encompasses the values for cellulose and the other polysaccharides, notably the pentosanes, together known as hemicelluloses.[24]

The comparative results for the general average only show statistical differences for the influence of the production model (Table 2). This difference was highly significant at the 1% level. The wood from the conventional production system presented around 5% greater polysaccharide content compared with the silvopastoral system. With relation to the influence of the species, no significant differences were observed, only a tendency for *E. urophylla* to exhibit higher values for the holocellulose level, compared with the *E. urophylla x E. grandis* hybrid.

Note that basic density is closely related to the chemical composition of wood. In this study, basic density showed a positive correlation with the holocellulose level and a negative relation to lignin content (Tables 1 and 2). Keeping in mind that the objective of the pulping process is the selective removal of lignin and the liberation of the fibrous portion of the wood, higher polysaccharide levels, and lower lignin levels will allow for better pulping performance in terms of yield and alkali consumption.

With regard to ash content in the wood, Freddo[25] indicates that in trees, the amount of these elements varies according to species, availability in the soil, individual requirements of each species and the time of year. In this study, significant differences were witnessed (Table 2) at the 1% level solely for the production model. High significance was detected with a 29.6% increase in ash content for the silvopastoral system over the conventional system. This occurrence of wider spacing generating higher ash content in the wood may be related to the greater availability of nutrients in the soil, resulting from less competition among plants in the wider spacing.

Barcellos *et al.*[2] commented that the more available mineral nutrients are in the soil, the more available these nutrients will be in the wood. The higher level of ash in wood from silvopastoral spacing can be related to greater growing space, which provided different growth conditions that affected the chemical properties.[17]

For the pulp industry, wood with a low mineral content is desirable because these minerals may constitute contaminants, which, upon accumulation in the process, cause problems, such as corrosion, erosion and clogging, leading to a shorter productive life for the material and production losses, especially in factories with a closed water cycle.[26]

Effect of forest production models on kraft pulping of *E. urophylla* and *E. urophylla x E. grandis*

The results obtained from the cooking processes allowed us to detect the influence of the treatments with respect to the screened pulp yield, which was calculated as the difference between gross yield and the level of reject. In this analysis, significant differences at the 1% level for the production model and 5% for the interaction of treatments are clearly visible (Table 3).

This statistical difference can be explained in a comparison among some properties of wood that also showed statistical differences for the production models, such as basic density, NaOH solubility and holocellulose content. The highly significant difference due to the production model can be explained by the basic density and the unique chemical composition of the wood, as observed above (Tables 1 and 2).

The authors Barrichello and Foelkel,[27] Queiroz *et al.*,[14] Trugilho *et al.*,[15] Santos and Sansígolo[16] and Gouvea *et al.*[12] stated that the influence on the screened yield for *Eucalyptus* species could be directly related to the basic density and chemical properties of the wood, which agrees with the findings of this study.

In the kappa number analysis, which is frequently determined in kraft pulping industries to assess the level of residual lignin in pulp, a higher kappa number indicates higher residual lignin content and *vice versa*.

Table 1
Analysis of variance for dendrometric properties

Source of variation		Mean tree volume over bark, %	F test	Bark volume, %	F test	Average basic density, g/cm^3	F test
Species	*E. urophylla*	0.222	0.98^{ns}	10.21	4.32^{ns}	0.482	10.08**
	E. urophylla × *E. grandis*	0.235		11.21		0.452	
Production model	Conventional	0.227	0.04^{ns}	9.92	10.70**	0.479	6.38*
	Silvopastoral	0.230		11.49		0.454	
Interaction between species and production model			0.62^{ns}		1.99^{ns}		10.64^{**}

^{ns} not significant, *significant at 5%, **significant at 1%

Table 2
Analysis of variance for chemical properties

Source of variation		Solubility in 1% NaOH, %	F test	Lignin, %	F test	Holocellulose, %	F test	Ash content, %	F test
Species	*E. urophylla*	12.52	0.62^{ns}	23.7	3.05^{ns}	76.69	2.36^{ns}	0.32	0.84^{ns}
	E. urophylla × *E. grandis*	12.91		24.2		75.73		0.30	
Production model	Conventional	11.92	10.36**	23.7	3.82^{ns}	78.08	35.08**	0.27	32.25**
	Silvopastoral	13.50		24.2		74.35		0.35	
Interaction between species and production model			2.86^{ns}		0.00^{ns}		0.22^{ns}		0.07^{ns}

^{ns} not significant, *significant at 5%, **significant at 1%

Table 3
Analysis of variance for kraft delignification

Source of variation		Screened yield, %	F test	Kappa number	F test	Specific wood consumption, m³ wood/tonne	F test
Species	*E. urophylla*	47.69	0.87^{ns}	17.74	0.19^{ns}	4.49	0.34^{ns}
	E. urophylla × *E. grandis*	48.17		18.71		4.60	
Production model	Conventional	49.41	0.01**	17.76	0.21^{ns}	4.33	0.01*
	Silvopastoral	46.63		18.69		4.75	
Interaction between species and production model			0.10*		0.56^{ns}		0.00^{**}

^{ns} not significant, *significant at 5%, **significant at 1%

This analysis shows the degree of delignification in the pulp after pulping and indicates what the pulp bleaching process will be like.[12,14,15]

Both treatments showed no significant differences (Table 3). All kappa number values were near 18, which is usual for most companies. A comparison of the results indicated that the kappa number had a negative relation with basic wood density and a positive one with lignin content.

In the pulp industry, the specific consumption of wood is a fundamental economic factor, as it determines a number of raw materials, in cubic metres, that needs to go to the factory to estimate final pulp production.[28] For 18% of active alkali, we can see (Table 3) significant differences at the 5% level for the production model and at 1% for the interaction between treatments.

The silvopastoral production system had a 9.6% higher wood consumption than the conventional system. The high representative value in the interaction between species and production model are related to the basic density and screened yield. Trugilho *et al.*,[15] Gomide *et al.*,[22] Santos and Sansígolo[16] and Moraes[28] state that specific wood consumption in the pulp industry is dependent on various factors, such as basic wood density, wood yield in the pulping process and wood losses that occur in the preparation sector. In this study, the wood samples with the highest basic density were those that consequently represented the lowest specific wood consumption.

CONCLUSION

In this study, the analysis of *E. urophylla* and hybrid *E. urophylla* x *E. grandis* wood, obtained from trees grown by different forest production models, demonstrated that the silvopastoral system, compared with the conventional one, significantly altered certain characteristics and properties of the wood, and these differences were influenced more by the production model than by species. Therefore, it is clear that both the forest production model and the species are fundamentally important in forest planning, especially in relation to the quality of the raw material produced.

Regarding the dendrometric parameters of the trees from the two forest production models, the study revealed that the percentage of bark in the volume of trees grown in the silvopastoral system was markedly higher than in the trees grown in the conventional system. As for species, the hybrid *E. urophylla x E. grandis* showed a tendency towards a higher bark percentage.

With regard to the influence of the production models on the physical and chemical properties of the types of wood studied, it can be concluded that:

a) The basic wood density in the silvopastoral production system (0.454 g/cm³) was significantly lower than the basic density of wood grown in the conventional system (0.479 g/cm³). Between the species, the density of *E. urophylla* (0.482 g/cm) was significantly higher than that of the hybrid *E. urophylla x E. grandis* (0.452 g/cm³) for both spacings.

b) The wood from the silvopastoral production system showed 1% S_{NaOH} (13.50%), lignin (24.2%), holocellulose (74.35%) and ash (0.35%). Except for the value for lignin, all the other components showed significant differences for the trees grown in the conventional system: 11.92%, 23.7%, 78.08% and 0.27%, respectively.

c) The chemical analyses disclosed better kraft pulping properties of the wood grown in the conventional system and for the *E. urophylla* wood. The chemical composition was mainly affected by the forest production model and then by the species.

Regarding the influence of the production model on the kraft pulping of wood, the following conclusions could be drawn:

a) For the conventional system, a screened yield of cellulose (kappa number = 17-18) of 49.41% and specific wood consumption of 4.33 m^3/tonne of pulp were obtained. The corresponding values for the silvopastoral system were of 46.63% and 4.75 m^3/tonne of pulp.

b) The kraft pulping results for both forest production models showed very good and expected relations with regard to basic density and chemical analysis of the wood.

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