Growth, production and wood quality in integrated crop-livestock-forest and monoculture systems

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ABSTRACT: This work aimed to evaluate the growth, production and wood quality a clonal hybrid (*Eucalyptus grandis* x *Eucalyptus urophylla*) produced in integrated crop-livestock-forest systems (iCLF) and monoculture. The study was carried out in an iCLF system and a monoculture stand, both in the municipality of Sinop, state of Mato Grosso, Brazil. Diameter (at 1.3 m height), total height and production (volume) of trees were evaluated, along with wood quality (growth strains and wood density). The parameters of the trees in the iCLF system were analyzed according to the different positions of the trees in the plantation (lines and between rows), and were compared with the quality of the wood produced in the traditional system (homogeneous plantation). The results indicated an approximate yield of 22.98 m^{-3} ha^{-1} $year^{-1}$ for iCLF and 32.15 m^{-3} ha^{-1} $year^{-1}$ for traditional planting. The longitudinal residual deformation LRD (growth stress) in the iCLF system was higher for the central trees of the stand. The canopy projection in monoculture plantation and the central line of the iCLF system presented more homogenous distribution in relation to the other planting lines. The trees produced in the integrated system presented greater wood density than those produced in the monoculture.

Key words: non-destructive analysis; wood quality; agroforestry systems

Crescimento, produção e qualidade da madeira em sistemas de integração lavoura-pecuária-floresta e monocultivo

RESUMO: O trabalho teve como objetivo avaliar o crescimento, a produção e a qualidade da madeira do híbrido clonal (*Eucalyptus grandis* x *Eucalyptus urophylla*) produzido em sistemas de integração lavoura-pecuária-floresta (iLPF) cultivado em renque triplo e, monocultivo produzido em espaçamento de 3,50 x 3,00 m. O estudo foi desenvolvido em um sistema iLPF e em um monocultivo, ambos planejados no município de Sinop-MT. Foi avaliado o crescimento em diâmetro a 1,3 m de altura e altura total, a produção (volume) e a qualidade da madeira (tensões de crescimento e a densidade da madeira) através de técnicas não destrutivas. A análise destes parâmetros foi em função das diferentes posições das árvores nos plantios (linhas e entre linhas do plantio no renque), e comparada à qualidade da madeira produzida pelo sistema tradicional (plantios homogêneos). No sistema iLPF a produtividade foi estimada em 22,98 m^{-3} ha^{-1} ano^{-1} e no monocultivo 32,15 m^{-3} ha^{-1} ano^{-1}. Nos resultados da deformação residual longitudinal – DRL (tensões de crescimento), verificou-se para o sistema iLPF maior deformação nas árvores centrais do renque. A projeção de copa dentro do plantio homogêneo e na linha central do sistema iLPF apresentou distribuição mais homogênea em relação as demais linhas do plantio. As árvores produzidas no sistema iLPF apresentam densidade da madeira superior àquelas produzidas no monocultivo.

Palavras-chave: análise não-destrutiva; qualidade da madeira; sistemas agroflorestais

Introduction

The integrated crop-livestock-forest (iCLF) system intensifies land use by producing grains, forage plants, livestock, wood and non-wood products in the same area (Balbino et al., 2011). These systems have been expanding due to the possibility of diversifying activities, reducing costs and increasing income of farmers (Alvarenga et al., 2010), in addition to presenting high potential for recovery of degraded areas (Oliveira et al., 2015; Mascarenhas et al., 2017).

Among the tree species used in commercial plantations with potential for use in the iCLF system, species of the genus *Eucalyptus* stand out for fast growth, genetic improvement through advanced technologies and research related to management (Lucas et al., 2015) and various uses of wood, such as firewood, charcoal, fence posts, pulp and paper, fiber and particle boards, construction of houses and furniture (Pereira, 2000; Oliveira et al., 2015).

However, although *Eucalyptus* has numerous attributes for timber purposes, there are limitations imposed by growth stresses, which are very common (Beltrame et al., 2012). These growth stresses are the result of the internal forces that act on the tissues of the trees, in order to keep them intact and erect. However, the high levels of growth stresses in the tree cause low yield in the production of sawn wood, due to the high incidence of cracks (Lima et al., 2004).

In integrated production systems, as is the case of iCLF, the atypical conditions to which trees are exposed, such as increased exposure to solar radiation, winds and shock from animals, can reduce the wood quality (Ferreira et al., 2020).

Among the various properties of wood, one of the most used to estimate quality and specify suitability for various uses is density. In view of the many uses of eucalyptus wood and the benefits of iCLF, it is important to study the quality of the wood produced in these production systems to enable correct indications regarding its use.

Nevertheless, due to the delay in harvesting the forest component in this system, techniques are needed that can predict the quality of this wood while trees are alive (nondestructive techniques). The most suitable techniques for this analysis are measurements of growth stresses.

Growth stresses are present in both conifers and hardwood trees. Among the hardwoods, the *Eucalyptus* species stand out the most, this being one of the main problems in wood processing. This phenomenon is linked to the characteristic fast growth of this genus (Braz et al., 2017).

Thus, the present study aimed to evaluate the growth, production and quality of the wood of the hybrid *Eucalyptus grandis x Eucalyptus urophylla* grown in an integrated crop-livestock-forest (iCLF) system in comparison with the same hybrid trees grown in a monoculture system, both in the state of Mato Grosso.

Material and Methods

Characterization of the study area

The study was carried out using an integrated crop-livestock-forest system (iCLF) and a monoculture stand, both planned and implemented by Embrapa Agrossilvipastoril in the municipality of Sinop, in the northern region of the state of Mato Grosso (11°51'43,74" S; 55°36'2,58" W). In the region the relief is flat, with average altitudes of 380 m, and predominance of red-yellow Latosol (Gregolin, 2017).

The climate of the region is of the Am type (tropical monsoon), with air temperature ranging from 18 °C to 32.5 °C and average of 25 °C (Alvares et al., 2013). The average accumulated precipitation ranges from 2,000 mm to 2,200 mm, and the average annual relative humidity is 76%, with predominant winds in the north and northeast directions during spring/summer and northeast and southeast during autumn/winter (Alvares et al., 2013; Boton et al., 2013).

Implementation and description of the experiment

The homogeneous experimental planting was implemented in February 2011 with 3.5 x 3.0 m spacing in an area of approximately 10 hectares. In the same year, the iCLF system was implemented, consisting of four rows of triple tree lines with 15 m between the rows, and 3.0 x 2.0 m spacing between trees, in an approximate area of 7.0 hectares.

For the iCLF system, the agricultural components were corn, soybean and cowpea, planted in the first, second and third year, respectively. In the third year, the forage species (*Brachiaria brizantha* cv. Marandu) was also planted to support the livestock component. From the fourth year onwards, only the forage species was maintained and the livestock component (dairy cattle - crossbred Holstein with gir heifers) was added, characterizing the silvopastoral system.

As a forest component for both areas, clone H13 was used, a hybrid of *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* W. Hill ex Maiden, also known as *Eucalyptus urograndis*.

Selection of the trees

For the analysis, 12 five-year-old trees were selected in the monoculture system, with the trees on the edges (three rows) being rejected in the sampling. In the iCLF system, 36 trees were selected, 12 per row, distributed in the central, northern and southern exposures.

This division occurred to assess the influence of the production system (homogeneous or integrated) on the technical quality of the wood. The planting lines forming the row were analyzed separately, considering the three different exposures (Figure 1). In both systems, trees were selected that had straight and cylindrical trunks, no bifurcation and good phytosanitary conditions.
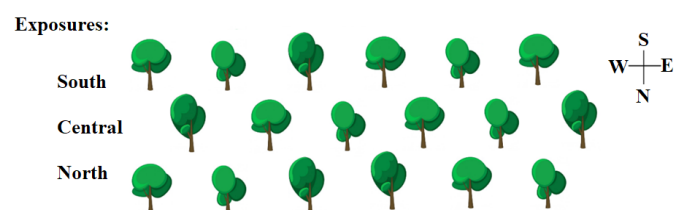

Figure 1. Implementation model of the iCLF system in triple row, with exposure of each of line in different directions.

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Dendrometric variables

The diameters were measured at height of 1.3 m (DBH), along with the total height, volume of wood with bark and the canopy projection. The DBH was obtained with a tape measure and the total height was measured with a Vertex III hypsometer. The volume of each tree was estimated means of height, diameter and a shape parameter of 0.50. The volume estimated per hectare was calculated by multiplying the average volume of the tree by the number of trees per hectare of each of the evaluated systems.

Tree canopy projection

The canopy projection was assessed with a Lemmon convex spherical densiometer (D), based on the four cardinal points (North, South, East and West). The densiometer consists of a convex mirror divided into 24 squares. For reading, each grid was subdivided into quadrants, and the number of quadrants of the grid reflecting the canopy was counted. The total of the squares was added and multiplied by 1.04, to obtain the projection estimate in meters (Lemmon, 1957).

Nondestructive analysis - wood density

The density of the wood was estimated with the help of a Pilodyn density meter, taken at breast height, in four directions according to the cardinal points, after removal of the bark (Figures 2A and 2B). The equipment penetrates a

Figure 2. Use of a Pilodyn meter to determine the density of wood from *Eucalyptus grandis* x *Eucalyptus urophylla* trees planted at Embrapa Agrossilvipastoril, in Sinop, Mato Grosso, Brazil.

2.5 mm diameter needle, driven by a spring with a constant force of 6 joules. In determining the basic density through the use of a Pylodin meter, the balanced equation proposed by Beltrame et al. (2012) is used to validate the effectiveness of the method (Equation 1).

$$DB = 679.52941 - 13.52125 \times r \qquad (1)$$

where: DB = basic density for each tree, in kg m^{-3}; r = puncture resistance, recorded on the Pilodyn scale, in mm.

Nondestructive analysis - growth stress

The growth stresses of the trees were estimated by measuring the longitudinal residual strain (LRS), which is an indirect measure of stresses, obtained with the aid of an extensometer (CIRAD-Fôret method) that provides digital data of this strain in millimeters (mm).

To perform the measurements, as recommended by Beltrame et al. (2012), first the bark of the trunk was removed at breast height. Then two pins spaced 45 mm apart in the direction of the grain were driven into the tree to attach a digital dial indicator. A 20 mm hole was made with a hand drill arch in the median position between the pins, where the wood tissues ruptured and the tension recorded by the device was released.

The readings of the LRS were performed in four positions (considering the cardinal points) around the tree trunk, following the orientation of planting to standardize the measurements, as recommended by Muneri et al. (1999).

Statistical analysis

Statistical comparisons were made for dendrometric variables and nondestructive wood quality tests comparing the iCLF and monoculture systems. Additionally, the different relative positions of the trees were compared between the iCLF lines. The data obtained in the evaluations were subjected to analysis of variance, and for the significant effects of treatment, the Tukey test was applied for comparison of means, at 5% probability. Before the analysis, the assumptions of normality, homogeneity of variance and data independence were evaluated. The program used for the analyses was the Action supplement, which analyzes the data in Microsoft Excel spreadsheets.

Results and Discussion

Dendrometric variables

In the dendrometric analysis, we observed that the trees from the integrated planting presented the best yield, with diameter of 16.77 cm and total height of 14.74 m, versus diameter of 13.84 cm and total height of 12.72 m for the monoculture (Table 1). Similar results were observed by Oliveira et al. (2015), who, when comparing the performance of the same hybrid in iCLF and monoculture systems, found greater height of trees in the integrated system at different ages (13, 18 and 25 months).

Table 1. Average values of dendrometric variables measured for *Eucalyptus grandis x Eucalyptus urophylla* trees grown in monoculture and iCLF systems in Sinop, Mato Grosso, Brazil.

System	DBH (cm)	Ht (m)	V (m³ ha⁻¹)	CAI (m³ ha⁻¹ ano⁻¹)
Monoculture	13.84 ± 1.08 b	12.72 ± 0.79 b	91.86	22.96
iCLF	16.77 ± 1.39 a	14.74 ± 1.04 a	65.66	16.42

Where: DBH = Diameter at breast height, standardized at 1.3 m; Ht = total height; V = volume projection per hectare for iCLF and homogeneous; CAI = current annual increment; Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

The values found are similar to those reported by Matias (2016), when analyzing individuals of *Eucalyptus grandis* x *Eucalyptus urophylla* in an integrated system at six years of age. With spacing of 3 x 2 m, distance between rows of 20 m and triple lines, average values of 19.06 cm for DBH and volume of 0.31 m³ per plant were obtained. The superior performance of the integrated system can be attributed to lower plant density compared to the monoculture stand, due to the spacing between rows, where there is greater availability of resources (soil and nutrients) and less intraspecific competition (Oliveira et al., 2015; Mascarenhas et al., 2017).

When evaluating different spacing of *Eucalyptus* hybrids, Oliveira et al. (2009) found that the volume varies according to the different spatial arrangements in an agrosilvopastoral system, with differentiation of DBH and total height. Our results corroborate those.

In the iCLF system, there was no significant difference (p> 0.05) between the different exposures, for all variables studied. Mean DBH values ranged from 16.27 to 17.44 cm and total height from 14.63 to 14.78 m (Table 2).

As for production, the monoculture yielded 128.6 m³ ha⁻¹ while the iCLF system yielded 91.93 m³ ha⁻¹, with average annual increases of 22.98 m³ ha⁻¹ year⁻¹ for iCLF and 32.15 m³ ha⁻¹ year⁻¹ for traditional planting. This can be attributed to the higher density of plants compared to the iCLF, which is only concentrated in the rows.

Behavior similar to the present study was observed by Oliveira et al. (2015) when comparing the performance of *Eucalyptus* in monoculture and iCLF systems. Those results corroborated earlier findings by Oliveira et al. (2009), who when

comparing different types of spacing of a *Eucalyptus* hybrid, found that the volume was affected by the arrangements.

The canopy projection (measuring the tree canopy radius in four positions according to the exposure in the N, S, E, W directions) in monoculture and iCLF systems, on average, did not show significant difference (p> 0.05). However, there was variation in the distribution for the four cardinal points (Table 3). In the iCLF system, the greatest projection occurred along the North-South axis, while in the homogeneous system there was greater regularity of the projection.

In the iCLF system, the canopy of individuals in each line tended to project towards the side of greatest exposure (North or South), with the exception of the central line. The North line presented average values of 3.24 m and the South line showed 3.02 m (Table 4). This result is due to the lower density of trees per unit of cultivated area in the integrated system, which implies greater space for canopy growth, mainly in the lateral lines (Martins et al., 2002; Radomski & Ribaski, 2010). In the Southern hemisphere, the openings to the North generally receive higher incidence of sunlight throughout the year, which leads to higher metabolic activity of the trees, resulting in greater growth.

Nondestructive analysis - wood density

In the monoculture stand, the Pilodyn device registered values from 19.75 to 20.92 mm deep in the bark, while in the integrated system, values from 18.03 to 18.39 mm were found (Table 5).

Since the estimated density is a variable dependent on Pilodyn penetration, there was a difference between the values of homogeneous planting and the iCLF system (p <0.05). The values found for homogeneous system ranged from 0.397 to 0.423 g cm⁻³ while in the integrated system the values were from 0.431 to 0.490 g cm⁻³ (Table 6). The density results obtained are similar to those observed by Hsing et al. (2016), who studied five clones of *E. urophylla x E. grandis* and found mean density values ranging from 0.429 to 0.471 g cm⁻³.

The trees grown in the integrated system had higher wood density than those grown in the traditional system. This can

Table 2. Average values of the dendrometric variables measured for the iCLF system of *Eucalyptus grandis* x *Eucalyptus urophylla* in Sinop, Mato Grosso, Brazil.

Exposure	DBH (cm) NS	Ht (m) NS
Central	16.27 ± 1.55	14.63 ± 1.54
North	16.59 ± 1.31	14.81 ± 0.75
South	17.44 ± 1.11	14.78 ± 0.71

Where: DBH = Diameter at breast height; Ht = total height; NS: no statistical differences were detected (p> 0.05).

Table 3. Average values of canopy projection of *Eucalyptus grandis x Eucalyptus urophylla* trees grown in monoculture and iCLF systems in Sinop, Mato Grosso, Brazil.

System	Tree canopy projection (m)				
	North	Este	South	West	Average
Monoculture	2.07 ± 0.34 a	1.36 ± 0.50 a	1.16 ± 0.45 b	1.83 ± 0.53 a	1.60 ± 0.37 a
iCLF	2.28 ± 0.85 a	0.95 ± 0.50 b	2.05 ± 1.08 a	1.28 ± 0.31 b	1.64 ± 0.32 a

Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

Table 4. Average values of canopy projection measured for the iCLF system of *Eucalyptus grandis* x *Eucalyptus urophylla* in Sinop, Mato Grosso, Brazil.

Exposure	Tree canopy projection (m)				
	North	Este	South	West	Average
Central	1.76 ± 0.31 b	1.03 ± 0.34 a	1.63 ± 0.21 b	1.21 ± 0.18 b	1.41 ± 0.12 b
North	3.24 ± 0.72 a	0.72 ± 0.26 a	1.50 ± 0.10 b	1.04 ± 0.25 b	1.63 ± 0.17 ab
South	1.83 ± 0.41 b	1.09 ± 0.71 a	3.02 ± 1.44 a	1.59 ± 0.23 a	1.88 ± 0.40 a

Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

Table 5. Pilodyn penetration capacity (mm) of *Eucalyptus grandis x Eucalyptus urophylla* trees grown in monoculture and iCLF systems in Sinop, Mato Grosso, Brazil.

System	Pilodyn penetration (mm)				
	North	Este	South	West	Average
Monoculture	19.75 ± 0.87 a	20.33 ± 1.07 a	20.92 ± 1.24 a	20.92 ± 1.31 a	20.48 ± 0.81 a
iCLF	18.03 ± 1.56 b	18.19 ± 1.31 b	18.39 ± 1.52 b	18.25 ± 1.87 b	18.22 ± 1.37 b

Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

Table 6. Density estimated with a Pilodyn meter (g cm^{-3}) of *Eucalyptus grandis x Eucalyptus urophylla* trees grown in monoculture and iCLF systems in Sinop, Mato Grosso, Brazil.

System	Density (g cm^{-3})				
	North	Este	South	West	Average
Monoculture	0.412 ± 0.012 b	0.405 ± 0.015 b	0.397 ± 0.017 b	0.423 ± 0.018 b	0.403 ± 0.011 b
iCLF	0.436 ± 0.021 a	0.434 ± 0.018 a	0.431 ± 0.021 a	0.490 ± 0.025 a	0.433 ± 0.019 a

Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

be explained by the fact that these trees are more subject to the action of the weather, especially the action of winds. Wood in these conditions tends to have a higher percentage of gelatinous fibers, of slightly higher density due to the occurrence of driftwood (Washusen et al., 2001; Vidaurre et al., 2013). In addition, the passage of animals in this system causes frequent contact with trees during grazing. This causes the trees to produce a higher percentage of reaction wood (Ferreira et al., 2020).

Nondestructive analysis - Growth stress

LRS levels were similar between cultivation systems for most of the evaluated exposures. The only exception was the East exposure, where iCLF showed greater deformations when compared to the monoculture. Regarding the average behavior, the monoculture trees also showed lower values than those of the iCLF system (Table 7).

When studying LRS in a monoculture system of *Eucalyptus* spp. at different ages, Lima et al. (2004) found mean values of 0.071 mm, indicating less deformation compared to the average of that study. Similarly, Muneri et al. (1999), when evaluating the intensity of growth stresses through LRD, obtained mean values of 0.077 mm in a monoculture stand of *Eucalyptus cloeziana* at 4 years of age.

The average LRS values found in our study were clearly greater than the values reported by the authors mentioned above. This fact can be attributed to differences in species, location, age and incidence of winds, which can influence the occurrence of this metric.

The results observed in the iCLF system in the trees with different exposures did not show significant differences (p> 0.05) (Table 8). This indicates that the locations of the trees in relation to their exposure in the row do not interfere with growth stresses.

In the iCLF system, on average the total height and the diameter were greater in relation to the monoculture stand. The total volume of wood produced in the homogeneous system was higher than in the iCLF system, while the individual volume of trees was smaller. We also observed that on average, the highest densities and growth stresses were observed in trees in the integrated system, for all exposures. In analyzing *Grevillea robusta*, Martins et al. (2002) found that trees planted in single lines or on borders received a greater amount of light on the side of the canopy, so they ended up having the greatest development on the face exposed to sunlight, resulting in a shaft with asymmetric cross section and consequently low wood quality due to the formation of reaction wood.

Table 7. Longitudinal residual strain (LRS) of *Eucalyptus grandis x Eucalyptus urophylla* trees grown in monoculture and iCLF systems in Sinop, Mato Grosso, Brazil.

System	Longitudinal residual strain (mm)				
	North	Este	South	West	Average
Monoculture	0.121 ± 0.056 a	0.109 ± 0.041 b	0.132 ± 0.076 a	0.095 ± 0.061 a	0.114 ± 0.026 b
iCLF	0.172 ± 0.165 a	0.155 ± 0.067 a	0.133 ± 0.078 a	0.128 ± 0.071 a	0.147 ± 0.051 a

Means followed by the same letter in the columns do not differ statistically, according to the Tukey test at 5% significance.

Table 8. Longitudinal residual strain (LRS) for the iCLF system of *Eucalyptus grandis* x *Eucalyptus urophylla*, in Sinop, Mato Grosso, Brazil.

Exposure	Longitudinal residual strain (mm) [NS]				
	North	**Este**	**South**	**West**	**Average**
Central	0.19 ± 0.15	0.16 ± 0.06	0.15 ± 0.11	0.15 ± 0.07	0.16 ± 0.04
North	0.14 ± 0.06	0.15 ± 0.09	0.12 ± 0.06	0.13 ± 0.08	0.13 ± 0.04
South	0.19 ± 0.24	0.24 ± 0.06	0.13 ± 0.06	0.10 ± 0.05	0.14 ± 0.07

[NS]: no statistical differences were detected ($p > 0.05$).

Conclusions

The trees of the eucalyptus hybrid studied here (*Eucalyptus grandis* x *Eucalyptus urophylla*) grown in the iCLF system had higher wood density than those grown in the homogeneous stand.

The longitudinal residual deformations, resulting from growth stresses, were higher in trees grown in the iCLF system.

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