ADVANCES IN FORESTRY SCIENCE

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Yield and economic feasibility of *Eucalyptus dunnii* stands under different management regimes

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Original Article

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Keywords:
Coppicing

forest economy

Thinning

Palavras-chave:
Talhadia

Economia florestal

Desbaste

Received in
2023/01/18

Accepted on
2024/05/13

Published in
2024/07/01

DOI:
http://dx.doi.org/10.34062/afs.v11i2.14896

ABSTRACT: The aim of this study was to analyze volume yield, number of logs per assortment and economic feasibility of *Eucalyptus dunnii* stands under different management regimes. The stands are located in Fernandes Pinheiro, Paraná State, Brazil and cover a total area of 2.26 hectares, fragmented into three strata (treatments): A (8 years after coppicing regime), B (9-year old stand after two thinnings), and C (7-year old stand after one thinning). Diameters at breast height (d) of all trees and heights of 110 trees were obtained. The total height of the other trees was estimated by a hypsometric relationship. Tree volume was obtained through a taper function. For the economic analysis comparing the three strata, the periodic equivalent value (PEV) and the internal return rate (IRR) were evaluated considering an interest rate of 8%. The commercial volumetric estimates ranged from 156.61 to 375.53 $m^3\ ha^{-1}$. The stratum A yielded more logs, mostly for energy; stratum B yielded larger logs, and stratum C yielded similar number and volume of logs from all assortment classes. For economic analysis, PEV ranged from R$ 196.16 to R$ 1,255.79 ha $year^{-1}$, and IRR ranged from 12.73% per year (stratum A) to 21.35% per year (stratum C), based on a interest rate of 8%. It was concluded that the management condition of stratum C resulted in higher economic returns, with its product primarily destined for Sawmill 1.

Produção e viabilidade econômica de povoamentos de *Eucalyptus dunnii* em diferentes regimes de manejo

RESUMO: O objetivo deste estudo foi analisar a produção volumétrica, número de toras e a viabilidade econômica de povoamentos de *Eucalyptus dunnii* sob diferentes condições de manejo, considerando multiprodutos. Os povoamentos se localizam em Fernandes Pinheiro, Paraná, Brasil e possuem uma área total de 2,26 ha, fragmentado em três estratos: A (8 anos regime de talhadia), B (com 9 anos regime de condução com dois desbastes) e C (com 7 anos regime de condução com um desbaste). Por meio do censo, obtiveram-se os diâmetros de todas as árvores e alturas de 110 árvores. A altura total das demais árvores foi obtida pela relação hipsométrica. O volume foi obtido por meio de uma função de afilamento. Para a análise econômica comparando os três estratos foram avaliados o valor periódico equivalente (VPE) e a taxa interna de retorno (TIR) considerando uma taxa de juros de 8%. As estimativas de volume comercial variaram de 156,61 a 375,53 $m^3\ ha^{-1}$. O estrato A obteve maior quantidade de toras, sendo em sua maioria para energia, o estrato B gerou maior quantidade de toras e o estrato C obteve um equilíbrio entre as classes de sortimento, tanto para volume quanto para número de toras. Para análise econômica, o VPE variou de R$ 196,16 a R$ 1.255,79 ha ano^{-1} e a TIR variou de 12,35% a.a. (estrato A) a 21,35% a.a. (estrato C), com base em uma taxa mínima de atratividade de 8%. Concluiu-se que a condição de manejo do estrato C resultou em maior rendimento econômico, com seu produto destinado em sua maior parte para Serraria 1.

Introduction

The genus *Eucalyptus* is the most planted in Brazil, representing 76% of the planted forest area occupying 7.6 million of hectares (IBÁ, 2023). In 2022, 182 million m³ of wood was demanded in Brazil, for pulp and paper, energy, coal, veneer flooring, and furniture (IBÁ, 2023). The states in Brazil where *Eucalyptus* are planted the most are Minas Gerais, Mato Grosso do Sul and São Paulo (IBÁ, 2023). In Paraná, the genus Pinus is the most planted, occupying 713,524 hectares, while the genus Eucalyptus is the least planted, occupying 442,222 hectares (IBÁ, 2023), since it is a cold area and the genus *Eucalyptus* is limited by frost and cold winter temperatures. However, *Eucalyptus dunnii* is cold-adapted and suitable for the state (Dobner Jr. et al., 2017).

E. dunnii is native to the states of Queensland and New South Wales, in Australia, where the average temperature is 16 to 19 ºC, and precipitation ranges from 900 to 1,600 mm and the climate is classified as Cfa, with small Cfb and Cwb (Flores, 2016). *E dunni*i is grows fast, is frost-resistant, and yields even stands (Dobner Jr et al., 2017). Its wood is suitable for pulp and paper, veneer, coal, and furniture. Its Mean Annual Increment (MAI) ranges from 30 to 80 m³ ha year^{-1}, depending on several factors, such as genetics, spacing, and management (Glencross et al., 2011). Its wood presents average resistance and specific density of 500 Kg m^{-3} (Flores, 2016). The species can sprout and originate stands from coppicing, which is characterized by the emergence of sprouts from the stump and or roots, after the tree is cut (Freitag, 2013). Stands produced out of coppicing tend to be cheaper than stands produced from seedlings, known as high forest (Rocha et al., 2015).

To assess yield and economic viability of forests resulted from coppicing and high forest submitted to thinning, it is necessary to obtain biometric information from the stands. It is done by forest inventories, which quantifies and qualifies the natural resources existing in an area by applying the sampling theory (Comas and Mateu, 2014). In small areas, the inventory can be made by collecting data from all trees, which is referred to as census. From this data, models are fit into equations to estimate tree height (Ferraz Filho et al. 2018), volume (Oliveira et al. 2018) and taper (Scolforo et al., 2018).

As it is relatively difficult and time consuming to measure tree heights. A common practice is to measure d of all trees and a certain number of sample trees for height. Due to the high correlation between diameter and height, hypsometric models are fitted and used to predict the missing tree heights (Freitas et al., 2020).

From taper models assortments are estimated (Costa et al. 2016). The literature has some studies where taper models were fit, which can be used in similar circumstances. For example, the book "Compendium of volume and taper equations of planted and native forest species for Brazil" contain several volume and taper equations fitted for forests at several parts of Brazil (Figueiredo Filho et al., 2014). Therefore, these equations can be used to some extend to assess how silvicultural activities are affecting the forest.

To better conduct a stand, specific silvicultural activities are prescribed over the rotation. Thinning is one of them. When thinning a stand, trees are removed, which reduces competition for water, light and nutrients (Burkhart; Tomé, 2012). Thinning is affected by basically two factors: intensity and method. Intensity means how much the basal area is removed, and the method relates to how these trees removed will be selected (Weiskittel et al., 2011; Retslaff et al., 2012; Possato et al., 2016; Dobner Jr and Quadros, 2019).

To assess the effect of silvicultural prescriptions, such as thinning, stand attributes such as wood stock and assortments need to be precisely quantified, since they are crucial elements for economic analysis, along with market prices (Miranda, 2016). The economic aspects assessed in this study were Periodic Equivalent Value (PEV), Net Present Value (NPV), and Internal Return Rate (IRR). PEV means the periodic payments yielded from the project made over the rotation. It is useful to compare projects with different durations. NPV is the difference between revenues and cash outflows over the rotation in present values. IRR is how much return the project yields. If it is higher than the interest ratio, the project is profitable. Economic analysis are crucial for supporting management decisions, such as determining ideal rotation, spacing, species, fertilizing, thinning intensity and timing (Lopes, 2012). This study aimed to assess the economic feasibility of different management regimes for *E. dunnii* and to compare volumetric yield and number of logs produced by assortments classes.

Material and Methods

This study was performed in Fernandes Pinheiro, Paraná, Brazil. The climate is Cfb according to Koppen-Geiger classification, with average temperature as 17.7 °C, and precipitation of 1.463 mm (Alvares et al., 2013). Soil is red yellow podzol cambissoil (Ferronato, 2012). The *E. dunnii* forest is 2.26 ha, composed by three stands, henceforward referred as stratum A, B and C. Stratum A is 0.88 ha originated from coppicing 8 years ago. Stratum B is 0.65 ha, originated from seedlings planted 9 years ago, submitted to two thinning operations. Stratum C is 0.73 ha originated from seedlings planted 7 years ago, submitted to one thinning operation (Table 1). Data was collected through a census in the area. All diameter at breast height (d) were measured, using a metric tape. The total height (h) of 110 trees (40, 30 and 40 from stratum A, B and C, respectively) were measured. The total height of not-measured trees were estimated using a hypsometric equation, after three models were tested (Table 2).

Table 1. Stratus A, B and C for an *Eucalyptus dunnii* stands in Fernandes Pinheiro, Paraná state, Brazil.

Stratum	Area (ha)	Age (year)	Management	Spacing (m)	Thinning (%)	Age at thinning (year)
A	0.88	8	Coppice	2.0 x 1.5	-	-
B	0.65	9	High forest (2 thinnings)	2.5 x 2.5	20% + 20%	3 and 6
C	0.73	7	High forest (1 thinning)	2.5 x 2.5	35%	5

Table 2. Hipsometric models tested for the *Eucalyptus dunnii* stands in Fernandes Pinheiro, Paraná state, Brazil.

Model	Description	Reference
1	$\ln h = \beta_0 + \beta_1 \ln(d) + \varepsilon_i$	Stoffels (1955)
2	$\ln h = \beta_0 + \beta_1 (d^{-1}) + \varepsilon_i$	Curtis (1967)
3	$h = \beta_0 + \beta_1 \ln(d) + \varepsilon_i$	Henriksen (1950)

d = diameter at breast height (cm); h = tree total height (m); $\beta_{i's}$ = coefficients; ln = natural logarithm.

To select the best hypsometric equation, adjusted coefficient of determination ($R^2_{aj.}$) (1), standard deviation (S_{yx}%) (2), and residual dispersion graphics were assessed.

$$R^2_{aj.} = 1 - R^2 \times \left(\frac{n-1}{n-p}\right) \quad (1)$$

$$S_{yx}\% = \frac{Syx}{\bar{h}} * 100 \quad (2)$$

Where: R² is the coefficient of determination calculated from $R^2 = 1 - \frac{SQres}{SQtot}$; SQres is the sum of the residuals squared from the analysis of variance; SQtot is the total sum of squares from analysis of variance; n is the number of observed data; p is the number of parameters from the model; Syx is the residual error obtained from $S_{yx} = \sqrt{\frac{\sum(h_0 - h_e)^2}{n-p}}$; h_0 is the observed height (m); h_e is the estimated height; $\bar{h}$ is the average total height (m).

To estimate taper, the fifth-degree polynomial (Schöepfer, 1966) was used (3), as in Felde (2010), who also fitted the model for an *E. dunnii* stand, also described in Figueiredo et al. (2014):

$$\frac{d_i}{d} = 1{,}12536 - 3{,}11076\left(\frac{h_i}{h}\right) + 10{,}94487\left(\frac{h_i}{h}\right)^2 - 20{,}97802\left(\frac{h_i}{h}\right)^3 + 17{,}13939\left(\frac{h_i}{h}\right)^4 - 5{,}12465\left(\frac{h_i}{h}\right)^5 \quad (3)$$

Where: d = diameter at breast height (cm); h = tree total height (m); d_i = diameter at height h_i (cm); h_i = a height over the stem (m).

The assortments classes were set as in Table 3. Sawmill 2 class correspond to furniture use. Sawmill 1 class is wood used for construction and low-grade furniture. Energy class means coal and biomass for burning.

Table 3. Assortments for *Eucalyptus dunnii* according to diameter class considered in this study

Diameter Class	Use	Price (R$ m^{-3})
≥ 25 cm	Sawmill 2*	R$ 105,00
15 to 24.99 cm	Sawmill 1**	R$ 58,50
4 to 14.99 cm	Energy***	R$ 42,00

* For furniture and processed wood - sawn wood, OSB (oriented strand board), compensated.
** Used for civil construction (beam, columns) and low-level furniture.
***For energy – biomass and coal.

Using volume yield by assortment class, an economic analysis was made as in Rezende and Oliveira (2008). Implementation cost of each stratum was retrieved (Table 4). Costs and commercialization values of the wood were obtained through personal communication provided by the owner. The software *Planin Dunnii* was used for the analysis (EMBRAPA, 1995).

Table 4. Costs e revenues for each stratum over the years for *Eucalyptus dunnii* Maiden stands in Fernandes Pinheiro, Paraná state, Brazil.

Year	Operation	Costs and Revenues (R$ ha^{-1})		
		Stratum A	**Stratum B**	**Stratum C**
0	Soil preparation, ant control (pre- and post-planting), mowing, herbicide application	R$ 245,62	R$ 3,447.55	R$ 3,447.55
1	Replanting, topdressing fertilization, and ant control	R$ 2.332,93	R$ 1,603.99	R$ 1,603.99
2	Mowing, herbicide application, and ant control	R$ 576,98	R$ 249.70	R$ 249.70
3	Maintenance costs and ant control	R$ 481,41	R$ 247.16	R$ 247.16
4	Maintenance costs and ant control	R$ 109,22	R$ 109.22	R$ 109.22
5	Maintenance costs and ant control	R$ 109,22	R$ 109.22	R$ 109.22
6	Maintenance costs and ant control	R$ 109,22	R$ 109.22	R$ 109.22
7	Maintenance costs and ant control	R$ 109,22	R$ 109.22	**Revenue (R$ 20,168.23)**
8	Maintenance costs and ant control	**Revenue (R$ 8,694.93)**	R$ 109.22	-
9	**Revenue**	-	**(R$ 27,054.41)**	-

Costs and services were resumed; stratum A (coppicing, 8-year-old); stratum B (9-year-old high forest, 2 thinning); stratum C (7-year-old heigh forest, 1 thinning). The revenues are presented in parentheses.

For the economic analysis comparing the tree management regimes, periodic equivalent value (PEV) (5), and intern return ratio (IRR) (6) were used, as in Rezende and Oliveira (2008):

$$NPV = \sum_{j=0}^{n} R_j\,(1+i)^{-j} - \sum_{j=0}^{n} C_j\,(1+i)^{-j} \quad (4)$$

$$EPV = NPV\,\frac{(1+i)^t-1}{1-(1+i)^{-nt}} \quad (5)$$

$$\sum_{j=0}^{n} R_j\,(1+IRR)^{-j} = \sum_{j=0}^{n} C_j\,(1+IRR)^{-j} \quad (6)$$

Where EPV is periodic equivalent value; NPV is Net Present Value; i is interest rate, considered 8% in this study; n is duration of the project in years; IRR is internal return rate; R_j is the income in the year j; C_j is the cost in the year j.

Results

The hypsometric equations were fit, resulting in significant coefficients (β_0 and β_1) with 95% of confidence. Table 5 shows the coefficients, R²aj. and S_{yx} (%) statistics for each equation fit.

Table 5. Coefficients for the Stoffles, Curtis and Henriksen equations, R²aj and S_{yx} (%) statistics for *Eucalyptus dunnii* Maiden stands in Fernandes Pinheiro, Paraná state, Brazil.

Tested models	β_0	β_1	$R^2_{aj.}$	S_{yx} (%)
Stoffels	0.5416	0.8301	0.5912	15.88
Curtis	3.9555	-17.86	0.5815	16.06
Henricksen	-37.48	19.667	0.5938	15.82

β_0; β_1 = coefficients; $R^2_{aj.}$ = adjusted coefficient of determination; S_{yx} (%) = standard error of the estimate in percentage.

Adjustments of the equations were similar according to $R^2_{aj.}$ e S_{yx} (%). To analyse better the fit, dispersion graphics were analysed (Figure 1). Henriksen equation was selected.

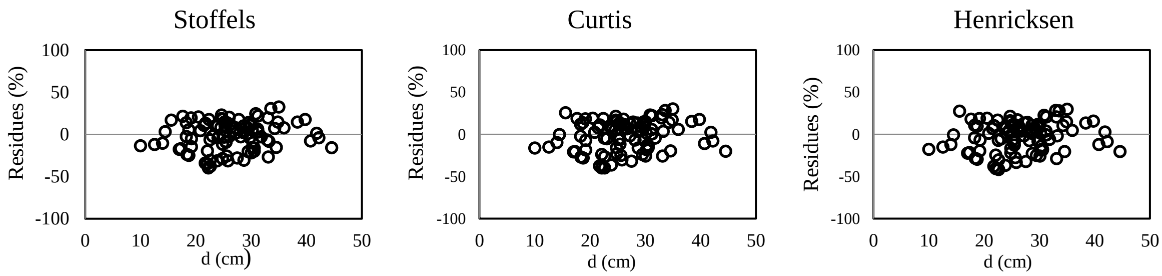

Figure 1. Residual dispersal charts for heights estimates using Stoffels, Curtis and Henriksen equations for *Eucalyptus dunnii* Maiden stands in Fernandes Pinheiro, Paraná state, Brazil.

Assortments in m³ (Figure 2) and the number of logs (Figure 3) on each assortment class were assessed for each stratum. Stratum B yielded the largest volume in sawmill 2 class, which is the one with greatest economic value. Besides, stratum B yielded the greatest volume per hectare. Stratum A yielded more logs, for energy, which has the lowest economic value. Stratum B resulted in greatest economic feasibility (Table 6).

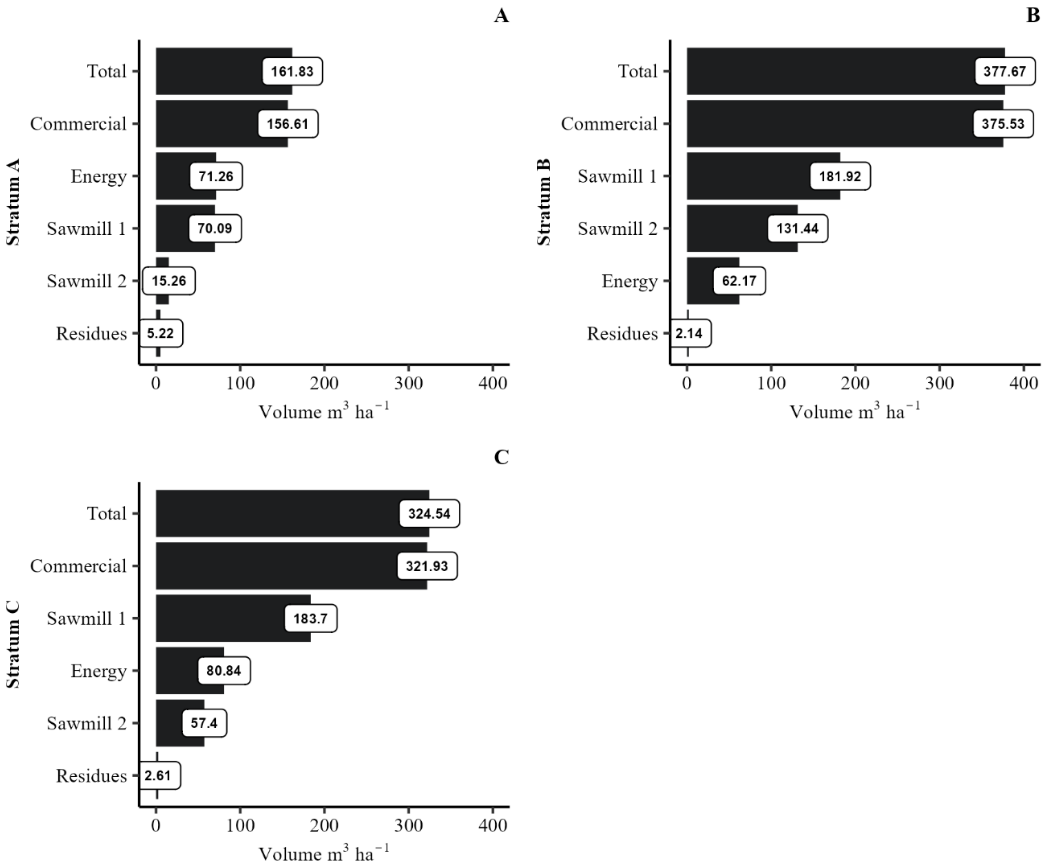

Figure 2. Estimated volume for each assortment class (m³ ha^{-1}) for *Eucalyptus dunnii* Maiden stands in Fernandes Pinheiro, Paraná state, Brazil.

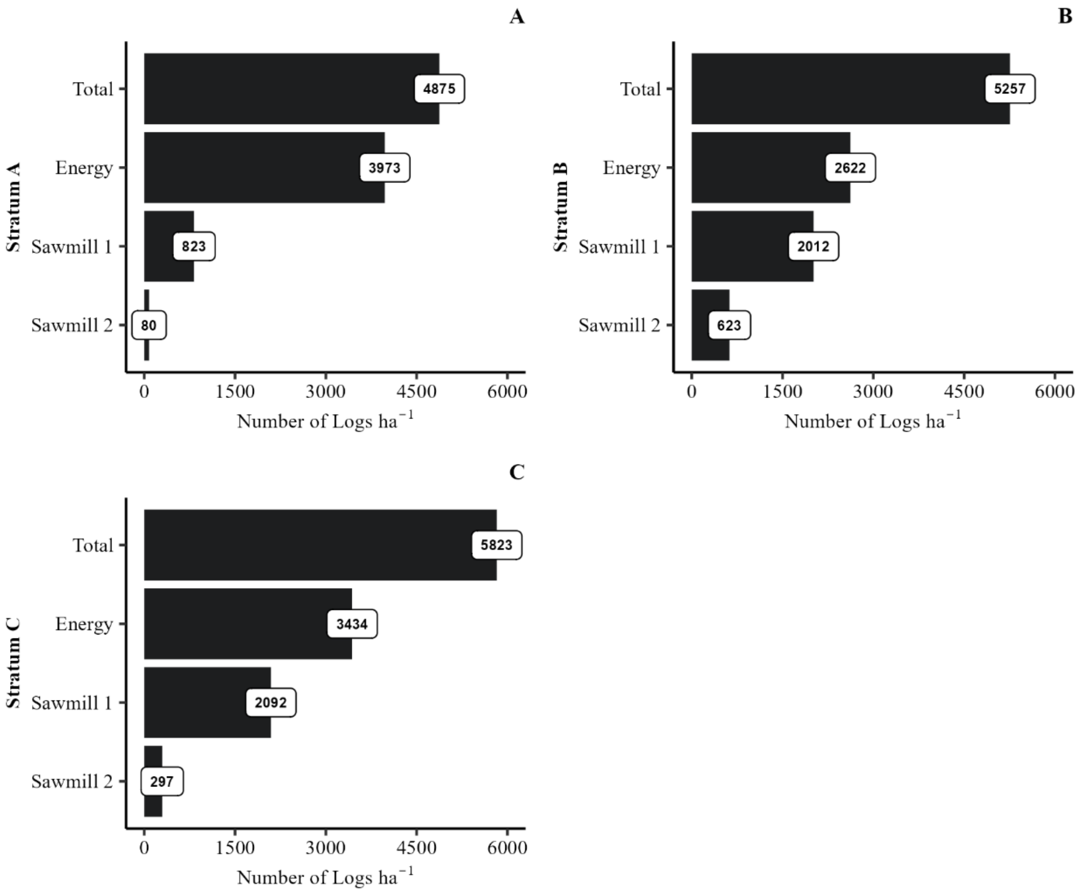

Figure 3. Number of logs for each assortment class for *Eucalyptus dunnii* MAIDEN stands in Fernandes Pinheiro, Paraná state, Brazil.

PEV for stratum A, B and C were R$196.16, R$1,255.79, and R$1,191.05 ha year^{-1}, respectively. IRR for stratum A, B and C were 12.73%, 19.87% and 21.35%, respectively (Table 6).

Table 6. EPV (equivalent periodic value) and IRR (internal return rate) for *Eucalyptus dunnii* Maiden stands in Fernandes Pinheiro, Paraná state, Brazil.

Stratum	**EPV (R$ ha year^{-1})**	**IRR (%)**
A	196.16	12.73
B	1,255.79	19.87
C	1,191.05	21.35

Stratum (A) (coppicing), Stratum B (9-year-old high forest, 2 thinnings); Stratum C (7-year-old high forest, 1thinning); PEV (periodic equivalent value); IRR (internal return rate).

Discussion

In the forest sector it is common to apply hypsometric equations instead of measuring all tree heights, which saves money and time on forest inventory campaigns. For eucalyptus plantations in Brazil, Stoffels, Curtis and Henriksen model are commonly used (Sousa et al., 2013; Santos et al., 2014; Souza et al., 2017). In this study, $R^2_{aj.}$ was 0.5912, 0.5815 and 0.5938 for the Stoffels, Curtis and Henriksen models, respectively. Normally the $R^2_{aj.}$ in hypsometric models is not higher than 0.80, because the correlation between height and diameter is not so strong as the correlation between diameter and volume (Freitas et al., 2020; Nicoletti et al., 2020). This suggests that changes in tree height are closely related to changes in stand variability over time (Chaves, 2013). Correlation between height and diameter weakens over time due to factors such as stand age, planting density, and site index. As trees in a stand continue to grow in diameter, their height tends to reach a plateau (Machado; Figueiredo Filho, 2014; Oliveira, 2020). Souza et al. (2017) assessed hypsometric fitting for 8-year-old *E. urophylla* and *E. grandis* stands in Pacajá, Pará, Brazil, and found $R^2_{aj.}$ values slightly higher than the values found on this study: 0.62, 0.66 and 0.61 for Stoffels, Curtis and Henriksen models. On the other hand, Sousa et al. (2013) studied hypsometric equations for 5-year-old *E. urophylla* stands from coppicing and seedlings in Vitória da Conquista, Bahia, Brazil, and obtained same R^2aj for Stoffels, Curtis and Henriksen models, 0.43, lower values than the values found in this study. Regarding S_{yx} (%), values were lower than 9% for the three models. Souza et al. (2017) studied plantations grown from coppicing and observed lower R^2_{aj} for the model of Henriksen (0.18) and similar values for the Curtis (0.55) and the Stoffels (0.56) models. S_{yx} (%) was 5.5% for the three models, lower than the values obtained in this study.

By analysing hypsometric relationships yielded from forests developed from coppicing, it is possible to concluded that hypsometric relationships tend to be less precise than hypsometric relationship from heigh forest stands, meaning that there is a large variation in tree height according to same diameter in stands produced from coppicing.

The spacing 2.0 x 1.5 m resulted in lower tree volume due to higher competition for water, light and nutrients (Burkhart e Tomé, 2012). In this research, Stratum A yielded low tree volume due to high competition, as well due to lower survival and site index.

Lower density spacings (less trees per hectare), such as 2.5 x 2.5 m yielded larger tree diameter and consequently larger tree volume (Rodrigues, 2017). Tree volume is an important variable because larger logs are more valuable in the market than small logs. Stratum B and C yielded more valuable logs than stratum A.

Thinned stands tend to yield greater tree volume than non-thinned stands due to greater living space available for each tree. Besides reducing competition, thinning is used as a means of promoting financing gains for the land owner before the rotation end. It contributes to creating income from wood before the end of the rotation and results in larger and more valuable logs at the end of the rotation (Paiva et al., 2016).

Beyond volume yield, thinning can affect wood chemical composition. For example, Zanuncio et al. (2013) assessed the chemical composition of *Eucalyptus urophylla x grandis* wood produced under different spacings and found that more dense stands yielded wood with greater energy power. Defining the goal of the forest is crucial before deciding the silvicultural operations that will take place in the forest, including deciding if the forest will or not be thinned, when that will occur and thinning intensity (David et al., 2017).

Stratum A yielded greater number of logs most suitable for energy (or pulp and paper, burning, and coal), which has lower market value. Thinning promoted an increase in the number of more valuable logs in strata B and C. Stratum C provided a greater number of logs in the sawmill 1 and energy assortment classes, and stratum B presented a greater number of sawmill 2 logs.

Regarding volume per hectare, stratum A yielded lowest volume in all assortment classes. Stratum B yielded lower number of logs, except in the sawmill 2 class. Stratum C produced more volume on the sawmill 1 and energy classes compared to other strata. Serpe et al. (2018) analysed assortments and economic feasibility and indicated that producing logs for energy compared to producing logs for sawmill is less profitable due to the multiuse sawmill logs provide (Costa et al., 2016; Serpe et al., 2018). By optimizing forest assortments to its best value, the company maximizes profit in opposition of using wood suitable for sawmill for less noble uses for example, energy. Besides, stratifying wood products into assortment classes makes the business less vulnerable to market fluctuations, since a forest can yield many products. Strata B and C promoted better distribution of commercial volumes across different assortment classes, which means less risk for the landowner and more flexibility to sell its wood. This is specially important nowadays, givenm the fact that using wood for energy to replace fossil fuel sources have been largely debated in developed countries, for example in England at the Drax Group. On the other hand, Stratum A specially produced logs for energy assortment class.

Since the stratum A, B and C has different ages, EPV and IRR analysis were used. EPV was R$ 196,16 ha $year^{-1}$, R$ 1.255,79 ha $year^{-1}$ and R$ 1.191,05 ha $year^{-1}$ for the stratum A, B and C, respectively. Strata B and C presented similar values in EPV, which may be explained by the method of implementation, since, they where implemented from seedlings instead of sprouting. IRR for the stratum A, B and C were 12,73%, 19,87% and 21,35%, respectively. When IRR is superior than the interest rate (8%), the project is feasible (Rezende; Oliveira, 2008). Furthermore, Stratum C yielded greater IRR compared to the other Strata, even in shorter rotation. Stratum A and B age's were 8 and 9 years, respectively. The greater the IRR, the more profitable the project is, since IRR makes the period of the project even, and allow analysing how much a project is more feasible than the other (Pedroso Filho et al., 2018). Stratum C resulted in greater IRR due to low thinning intensity, which costs money and due to more valuable logs at the evaluated age. In this research, as the investment costs for strata B and C were the same, the highest IRR represented the best project. On the other hand, Vitale and Miranda (2010) assessed a 17-year-old *E. dunnii* stand in

Parana, Brazil, and found EPV and IRR of R$ 3.832,55 ha year^{-1} and 35,83%. These values are affected by wood cost, supplies, wood quality at thinning, thinning intensity and timing, climate and market, among others.

Conclusions

Economic analysis showed that high forest and thinning regimes promoted higher volume per hectare and volume per tree, when compared to coppicing regime. Regimes with one thinning promoted even distribution of volume across all assortment classes, which is beneficial for diversifying risk obtaining multiple products. Two thinning's are recommended when the interest is to obtain wood with larger diameters logs for sawmill. Coppice regime is recommended for energy production. In this study, stratum C was considered the best economic management alternative.

Acknowledgements

We thank Zélia Jarki, Leandra Hopaloski and Renan Serbay for helping collecting data.

References

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JDM, Sparovek G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift, 22*(6): 711-728.

Burkhart HE, Tomé M. (2012). *Modeling forest trees and stands*. Springer Science & Business Media.

Chaves AGS. (2013). *Modelagem do Crescimento e da Produção de Tectona grandis Linn. F. até a Idade de Rotação. 2013, 86p. Dissertação (Mestrado em Ciências* Florestais) – Universidade Federal do Mato Grosso, Cuiabá.

Comas C, Mateu J. (2014). Forest Inventory. *Wiley StatsRef: Statistics Reference Online*, 1-9.

Costa EA, Finger CAG, Schneider PR, Hess AF. (2016). Função de afilamento e sortimentos de madeira para *Araucaria angustifolia*. *Ciência florestal*, 26(2), 523-533.

Curtis RO. (1967). Height-diameter and height-diameter-age equations for second-growth Douglas-fir. *Forest science*, 13(4), 365-375. doi: https://doi.org/10.1093/forestscience/13.4.365

David, HC, Péllico, S, Arce, JE, Corte, APD, Marinheski A, Araújo EJGD. (2017). Efeito da qualidade do sítio e do desbaste na produção de pinus. *Floresta e Ambiente*, 24. doi: https://doi.org/10.1590/2179-8087.096414

Dobner Jr M, Batista KM, Sartório I P, Arce JE, Quadros DS. (2017). Crescimento e desempenho econômico de *Eucalyptus dunnii* em diferentes sítios no planalto sul do Brasil. *Floresta*, 47(4), 397-406.

Dobner M, Quadros DSD. (2019). Economic performance of loblolly pine stands in southern Brazil as a result of different crown thinning intensities. *Revista Árvore*, 43(2): e430204. doi: 10.1590/1806-90882019000200004.

EMBRAPA. (1995). Software Planin - Planejamento Florestal Integrado, Colombo-PR, Brasil. URL http://www.cnpf.embrapa.br/software/.

Ferraz Filho AC, Mola-Yudego B, Ribeiro A, Scolforo JRS, Loos RA, Scolforo HF. (2018). Height-diameter models for *Eucalyptus* sp. plantations in Brazil. *Cerne*, 24: 9-17. doi:10.1590/01047760201824012466.

Ferronato MZ. (2012). *Avaliação da Percepção e Representação Espacial da Qualidade Visual da Paisagem na Flona-Irati/PR*. 2012, 95 f. Dissertação (Mestrado em Geografia) – Universidade Estadual de Ponta Grossa, Ponta Grossa.

Figueiredo Filho A, Machado SA, Miranda ROV, Retslaff FAS. (2014). *Compêndio de Equações de Volume e de Afilamento de Espécies Florestais Plantadas e Nativas para as Regiões Geográficas do Brasil*. Curitiba, 306 p.

Flores TB. (2016). *Eucalyptus no Brasil, Zoneamento Climático e Guia para Identificação*. Piracicaba: IPEF, 448 p.

Freitas FC, Silva JT, Silveira Pio N, De Lima RM B. (2020). Modelagem da relação hipsométrica em plantios de jatobá (*Hymenaea courbaril* L.) na amazônia central. *BIOFIX Scientific Journal*, *5*(2), 180-188.

Freitag A. (2013). *Crescimento de brotações de um clone de Eucalyptus urophylla x Eucalyptus grandis em função da disponibilidade de nutrientes no solo e da aplicação de fitorreguladores na cepa*. 2013, 82 f. Tese (Doutorado em Recursos Florestais) – Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba – SP.

Glencross KS, Palmer G, Pelletier MC, Nichols JD. (2011). *Growth response to thinning in two subtropical hardwood species*. Southern Cross University. 28 p.

Henriksen HA. (1950). Height/diameter curve with logarithmic diameter: brief report on a more reliable method of height determination from height curves, introduced by the State Forest Research Branch. *Dansk Skovforeningens Tidsskrift*, 35(4): 193-202.

IBÁ. *Relatório da Indústria Brasileira de Árvores, ano base 2023*. (2023). Brasília: IBÁ. 91 p.

Lopes HNS. (2012). *Crescimento e produção de eucalipto submetido à Desbrota, Interplantio e Reforma*. 2012, 65 f. Dissertação (Mestrado em Ciência Florestal) – Universidade Federal de Viçosa, Viçosa.

Machado SA, Figueiredo Filho A. (2014). *Dendrometria*. 2.ed. Guarapuava: UNICENTRO. 316 p.

Miranda ROV. (2016). *Modelagem de Árvores Individuais Para Povoamento Não Desbastado De Pinus taeda L*. 2016, 169 f. Tese (Doutorado em Ciências Ágrarias) – Universidade Estadual do Paraná, Curitiba.

Nicoletti MF, Lambert L, Soares PRC, da Silva Cruz G, Almeida BRS, Stepka TF. (2020). Equações hipsométricas, volumétricas e funções de afilamento para Pinus spp. *Revista de Ciências Agroveterinárias*, 19(4), 474-482.

Oliveira, XM. *Manejo e seu efeito na forma, estrutura e crescimento de povoamentos de Pinus taeda no sul do Brasil*. 2020. 188 p. Tese (Doutorado em Engenharia Florestal) – Universidade Federal de Lavras, Lavras – MG.

Oliveira XM, Ribeiro A, Ferraz Filho AC, Mayrinck RC, Lima RR, Scolforo JRS. (2018). Volume equations for Khaya ivorensis A. Chev. plantations in Brazil. *Anais da Academia Brasileira de Ciências*, 90 (4): 3285-3298. doi: 10.1590/0001-3765201820170852.

Paiva HN, Leite HG. (2016). *Desbastes e desramas em povoamentos de Eucalyptus*. Silvicultura do eucalipto no Brasil, 81.

Pedroso Filho JI, Biali LJ, Schneider PR, Farias JAD. (2018). Economic evaluation of afforestation projects with *Eucalyptus grandis* Hill ex Maiden implanted under different spacings. *Ciência Florestal*, 28(1): 240-248. doi: 10.5902/1980509831577

Possato EL, Calegario N, Nogueira GS, Melo EDA, Alves JDA. (2016). Estimate of stand density index for Eucalyptus urophylla using different fit methods. *Árvore*, 40: 921-929. doi: 10.1590/0100-67622016000500016.

Retslaff FAS, Figueiredo Filho A, Dias AN, Bernett LG, Figura MA. (2012). Growth and yield prognosis in diameter classes for thinning Eucalyptus grandis stands in Brazil south. *Árvore*, 36(4): 719-732. doi: 0.1590/S0100-67622012000400013.

Rezende JLP, Oliveira AD. (2008). *Análise Econômica e Social de Projetos Florestais*. Viçosa, MG: Universidade Federal de Viçosa, 389 p.

Rocha QS, Sales HL, Cabacinha, CD. (2015). Implantação e Condução de Povoamentos de Eucalipto em Propriedades Rurais na Região de Montes Claros – MG: Uma Análise Da Viabilidade Econômica. *Caderno de Ciências Agrárias*, 7(1): 75-88.

Rodrigues GG. (2017). *Fixação e alocação de carbono em plantações clonais de eucalipto sob diferentes densidades de plantio*. 2017, 112 f. Dissertação (Mestrado em Ciências), – Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba – SP.

Santos M, Neto AB, Paumgartten AE, Rodrigues R, Santos CR. (2014). Estimativa da relação hipsométrica para um povoamento de *Eucalyptus* "urograndis" no município de Moju, nordeste paraense. *Enciclopédia Biosfera*, 10(19): 1039-1048.

Serpe EL, Figueiredo Filho A, Arce JE. (2018). Impacto volumétrico e econômico para diferentes sortimentos em toras de pinus. *BIOFIX Scientific Journal*, 3(1), 199-203.

Scolforo HF, McTague JP, Raimundo MR, Weiskittel A, Carrero O, Scolforo JRS. (2018). Comparison of taper functions applied to eucalypts of varying genetics in Brazil: Application and evaluation of the penalized mixed spline approach. *Canadian Journal of Forest Research*, 48(5):568-580.

Sousa GTO, De Azevedo GB, Barreto PAB, Júnior, VC. (2013). Relações hipsométricas para *Eucalyptus urophylla* conduzidos sob regime de alto fuste e talhadia no Sudoeste da Bahia. *Scientia Plena*, *9*(4):1-7.

Souza AS, Santos JX, Souza DV. (2017). Modelagem da relação hipsométrica para um povoamento do híbrido de eucalipto na amazônia brasileira. *Biofix scientific journal*, 2(1): 44-53.

Stoffels, A. (1955). Die Genauigkeit der Bestimmung der Stammzahl pro Hektar durch Messung von Stammabständen. Forstwissenschaftliches Centralblatt, 74(7): 211-218. doi: https://doi.org/10.1007/BF01821578

Vitale V, Miranda GM. (2010). Análise comparativa da viabilidade econômica de plantios de *Pinus taeda* e *Eucalyptus dunnii* na região centro-sul do Paraná. *Floresta*, 40(3): 469-476.

Weiskittel AR, Hann DW, Kershaw Jr JA, Vanclay JK. (2011). *Forest growth and yield modeling*. John Wiley & Sons.

Zanuncio AJV, Colodette JL, Gomes FJB, Carneiro ADCO, Vital BR. (2013). Composição química da madeira de eucalipto com diferentes níveis de desbaste. *Ciência Florestal*, 23(4): 755-760. doi: https://doi.org/10.5902/1980509812359