ORIGINAL ARTICLE

Financial impact of silviculture management regime flexibilization under risk conditions

Impacto financeiro da flexibilização do regime de manejo florestal sob condições de risco

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Abstract

Determining the harvesting age of a forest is one of the most important decisions in the set of management techniques in order to achieve maximum productivity or maximum profitability. The traditional methodology generally used to determine the optimal forest management regime does not capture the uncertainties to which forest investments are subject. The present study aims to incorporate said uncertainties to the traditional methodology by using the Monte Carlo method in selecting the optimal management regime in small forest farmers' plantations. Eucalyptus production was analysed using the following financial indicators: Equivalent Annual Annuity (EAA), Internal Rate of Return (IRR) and Average Production Cost (APC). We analysed 20 management regimes, their production cycles undergoing one or two rotations, and the harvesting ages of each rotation ranging from six to nine years. Wood price and productivity were the risk variables used, and loss of productivity in the second rotation was analysed in three different scenarios. @Risk software was used to perform 100,000 simulations. The deterministic analysis of the modal project (cycle of two rotations, at seven years each) showed a return of up to US\$ 414.07 per hectare/year, therefore presenting it feasible in all scenarios studied. Results indicated that optimal management regime varies according to wood price and productivity expected, that profit when adopting the optimal regimen increased as productivity losses increased in the second cut, that high revenue (high productivity and/or wood price) scenarios tend to bring forward optimal harvesting age and even eliminate the second rotation of the silvicultural regime, but the opposite is also true.

Keywords: Eucalyptus; Economically optimal harvesting age; Monte Carlo method.

Resumo

Determinar a idade de colheita de uma plantação florestal é uma das decisões mais importantes do conjunto de técnicas de manejo para obter a máxima produtividade ou rentabilidade. As técnicas normalmente utilizadas para determinar a o regime de manejo economicamente ótimo não captura as incertezas as quais os investimentos florestais estão sujeitos. O objetivo deste estudo é incorporar as incertezas à metodologia tradicional utilizando o método de Monte Carlo para selecionar os regimes de manejo economicamente ótimos em plantações florestais de pequenos produtores. A produção de eucalipto foi analisada por meio do Valor Anual Equivalente (VAE), da Taxa Interna de Retorno (TIR) e do Custo Médio de Produção (CMP). Vinte regimes de manejo foram analisados, com ciclos de produção contendo uma e duas rotações, e idades de corte variando de seis a nove anos em cada rotação.

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As variáveis de risco consideradas foram o preço da madeira e a produtividade, sendo a perda de produtividade no segundo corte analisada em três diferentes cenários. Um total de 100.000 simulações foram executadas no software @RISK. A análise determinística do sistema de produção modal (ciclo com duas rotações, com colheita aos sete anos cada) apresentou um retorno de US\$ 414,07 por hectare ano, sendo economicamente viável em todos os cenários analisados. Os resultados indicaram que o regime de manejo economicamente ótimo varia com o preço da madeira e a produtividade esperada, que o retorno financeiro aumenta quando o regime economicamente ótimo é adotado de acordo com a perda de produtividade na segunda rotação, que cenários com elevada receita bruta (alto preço e/ou produtividade) tendem a alongar a idade economicamente ótima de corte e até eliminar a execução da segunda rotação no regime de manejo, sendo o contrário também verdadeiro.

Palavras-chave: Eucalipto; Idade economicamente ótima de colheita; Método de Monte Carlo.

INTRODUCTION

Productivity of Brazilian forest plantations has increased significantly, bringing the country's forestry into the spotlight. The total plantation area covers over 10 million hectares, 75% of which are eucalyptus varieties (Instituto Brasileiro de Geografia e Estatística, 2017). The forest-based industry in Brazil has become increasingly dependent on silviculture for the production of woody material, which replaces the use of wood from native forests (Fischer & Zylbersztajn, 2012).

Determining a stand's management regime and rotation is one of the most important steps in the set of forest management and planning techniques. This is due not only to its main objective – the maximization of profits – but also to the high value investment related to this kind of project (Resende et al., 2004). An investor will have increased costs of production and/or loss of revenue when cutting the forest outside its economically optimal harvesting age, therefore failing to achieve maximum return on the investment made.

Traditional investment evaluation techniques, such as discounted cash flow (DCF), are deterministic and commonly used for determining the rotation of the forest. Those techniques do not capture uncertainties, leading managers to search for methods and techniques that allow for risk variables to be incorporated into the analysis of projects (Santos & Pamplona, 2005).

The Monte Carlo method (Metropolis, 1987) is a widely used simulation technique to analyse problems that can be represented by stochastic processes (Moreira et al., 2017; Platon & Constantinescu, 2014; Silva et al., 2014)

This work aims to evaluate how risk variables behaviour – more specifically wood price and productivity – can affect a eucalyptus forest's economically optimal harvesting age. It also aims to identify what gain there is for a farmer to adjust the silvicultural regime (harvesting age) to the forest's economic and productive scenario, rather than to maintain a production modal harvesting age.

MATERIAL AND METHODS

Characterization and study area location

The research site is located in Santa Cruz do Sul (RS), a city in the south of Brazil, which has an area of 733.4 km² and had an estimated population of 127,429 in 2017 (Instituto Brasileiro de Geografia e Estatística, 2017). The altitude in the region is 73, its temperatures varying between 15,1 °C and 25 °C in its CFA subtropical climate, and average annual rainfall of 1.311mm (Climate-Data, 2017). Tobacco leaf is the area's main source of revenue, employment and income, and the region is a tobacco industry world hub (Corralo, 2017).

Data collection

Moreira et al. (2017) performed the production system characterization and data collection after visiting small eucalyptus plantation farmers; specialists in the dissemination of silvicultural technology from institutions representing farmers; and from tobacco

production industries operating in the region, during the second semester of 2015 and the first semester of 2016.

Production Modal

Due to the heterogeneity of silvicultural practices used by forest farmers in the region, some of which are inconsistent with technical recommendations (inadequate spacing, ant control techniques, weed competition control, and lack of proper fertilization), Moreira et al. (2017) decided to create a production modal system for small farmers, which was based on the technical recommendation used in silvicultural projects of family farmers, and subsequently validated by local experts.

The production modal delineated aims to produce firewood for drying tobacco leaves in small rural family properties, being part of the firewood supply chain for energy (Simioni et al., 2018). The firewood production is mainly for self-consumption purposes, and the surplus traded with nearby farmers (3km average transport radius). The modal property has about 14.5 hectares, 1.5 hectares being of eucalyptus plantation. The exchange rate was the annual mean of 2016, 3.49 R\$ US\$⁻¹ (Instituto de Pesquisa Econômica Aplicada, 2018).

The silvicultural regime consists of two rotations at seven years of age each, coming to a total 14-year cycle, in a low-tech system. The establishment costs, which encompass ant control, site preparation (subsoiling combining disking and bedding), pre- and post-establishment fertilization, and semi mechanized weed control between planting lines add to 639.35 US\$/ha in Year 0 (establishment), and 14.92 US\$/ha in Year 1 of the cash flow.

Seven years after establishment the farmer does a semi mechanized harvest by cutting with a chainsaw and extraction with an ox cart or an agricultural tractor. Harvesting and transportation cost was estimated at 8.48 US\$ (stereo meter - st)⁻¹, and 38.1 working days were needed to harvest one hectare. The initial costs of the second rotation are 139.42 US\$ ha⁻¹ in Year 7 (year 0 of the second rotation cycle), 14.92 US\$ ha⁻¹ in the eighth and 39.80 US\$ ha⁻¹ in the ninth year of the silvicultural regime.

The authors considered a land lease cost of 143.17 US\$ ha⁻¹ year⁻¹; costs with administration, road and firebreaks maintenance were not considered due to small scale of production.

Definition of silvicultural management regimes

The simulations run used production cycles with one or two rotations, ranging from six to nine years of harvesting age in both rotations, resulting in 20 management regimes for assessing the economically optimal regimen. Table 1 shows the management regimes schemes with their respective codes.

Table 1: Ages of first and second cuts and management regimes codes (P = first cut; S = second cut).

Code		1 st Cut			
		6	7	8	9
2 nd Cut	0	P6S0	P7S0	P8S0	P9S0
	6	P6S6	P7S6	P8S6	P9S6
	7	P6S7	P7S7*	P8S7	P9S7
	8	P6S8	P7S8	P8S8	P9S8
	9	P6S9	P7S9	P8S9	P9S9

* Small farmer's modal management regime adopted.

Experts reported the expected productivity (Annual Average Increment-AAI) at seven years in the first rotation was 35 (cubic meters - m³) ha⁻¹ year⁻¹ at its minimum, 45 m³ ha⁻¹ year⁻¹ expected value (mode) and 50 m³ ha⁻¹ year⁻¹ maximum productivity. The yield table of the modal regime (AAI of 45 m³/ha.year) was adjusted in the software

SisEucalipto by inserting the number of trees and adjusting the Site Index in the software until the desired AAI in the harvesting age was obtained. The same yield table assumptions were used to calculate the second rotation yield table, reducing the percentage of productivity loss in the analysed scenario (loss of 0%, 15% or 30% in volume). The cubic meter conversion to stereo meter used was 1.42 st m⁻³.

The minimum acceptable rate of return (MAR) used for the capital real return (above inflation) was 3.8% per year, since cash flows were calculated at real prices (Moreira et al., 2017).

The Monte Carlo Method

According to Martins et al. (2015), Monteiro et al. (2012) and Moura (1997), the execution and analysis of the Monte Carlo method has the following steps: a) model definition, where the problem and its characteristics are modelled in a spreadsheet, and relation between the model's variables is established; b) identifying model's uncertainties, that is, input variables that exert significant meaning in its result. Once these variables are identified, a probability distribution that best fits that data series behaviour is assigned to it; c) identification of variables of analysis or output variables, that is, the variables whose behaviour and results interest the decision-maker; d) simulation execution, where the model is solved N times, resulting in values for each input variable and recording the output variables' values for analysis; e) analysis of the simulated model, where frequency and accumulated frequency distributions for the output variables are obtained; f) decision-making, which is based on information garnered along with the other relevant aspects to the project.

Input variables

Input variables are uncertain (or risk) variables whose values should be drawn from probability distributions. Estimates of wood price values (R\$ st⁻¹) and productivity (m³ ha⁻¹) were considered risk variables due to their high impact on profitability variation (Moreira et al., 2016). The third source of risk considered was loss of productivity in the stand's second rotation, on cycles with two rotations, and scenarios modelled showed loss of 0% (S-00%), 15% (S-15%) and 30% (S-30%) of productivity applied directly in the production table of the second rotation. Literature on productivity losses in the second rotation for *Eucalyptus* spp stands and productivity studies for the region (Finger, 1997) served as foundation for said scenarios, which were implemented in the model through @RISK's RISKSIMTABLE () function. Doing so ensured that values drawn for the risk variables of each simulation were the same for each loss of productivity scenario evaluated in the second rotation.

Triangular distribution was used to represent wood price and expected productivity in the first rotation in the seventh year. Minimum, mode and maximum wood prices were 14.33 US\$ mst⁻¹, 15.19 US\$ mst⁻¹ and 18.62 US\$ mst⁻¹, respectively.

Productivity risk was implemented as follows: conversion of continuous triangular distribution of expected productivity at seven years, with minimum, mode and maximum productivity (AAI) of 35m³ ha⁻¹, 45 m³ ha⁻¹ and 50 m³ ha⁻¹ respectively, to a discrete distribution; to do so, productivity intervals of one m³ ha⁻¹ each were made and the midpoint of each interval was calculated, being considered as the expected productivity of that interval; each interval's occurrence probability was calculated through the cumulative triangular distribution formula for maximum and minimum value of each interval, and its occurrence probability was given by the difference in the accumulated probability values of the interval's higher and lower limits; the site index was adjusted on SisEucalipto for each productivity interval so that the expected productivity at the seventh year of the first rotation reached the midpoint interval value; thus, the production table for each productivity interval was estimated, as shown in Table 2.

Table 2: Yield table for each Average Annual Increment (AAI) class and their probability occurrence.

AAI (m ³ ha ⁻¹)		35,5	36,5	37,5	38,5	39,5	40,5	41,5	42,5	43,5	44,5	45,5	46,5	47,5	48,5	49,5	Productivity (m ³ /ha)
Probab.		0,6%	1,9%	3,2%	4,4%	5,7%	7,0%	8,3%	9,5%	10,8%	12,1%	12,8%	10,4%	7,4%	4,4%	1,5%	
Age (years)	2	20	21	22	23	24	24	25	26	27	28	29	30	30	31	32	
	3	60	62	64	66	68	70	73	75	77	79	82	84	86	89	91	
	4	108	112	115	119	123	127	130	134	138	141	146	149	153	157	161	
	5	158	163	168	173	178	184	188	193	198	203	209	214	219	224	230	
	6	206	212	218	224	230	237	243	249	255	261	267	273	279	286	292	
	7	249	256	263	269	276	284	291	297	304	311	319	326	332	339	346	
	8	286	294	302	309	317	325	333	340	348	355	363	371	378	386	393	
	9	319	328	336	344	352	361	369	377	385	393	402	409	417	425	434	

In each simulation, @RISK drew the productivity interval in the discrete distribution and replaced the first rotation yield table with corresponding values of selected productivity; the second rotation yield table was calculated by applying each scenario's productivity loss percentage to the corresponding first rotation yield table; the selected yield table values, together with the price drawn were inserted in all management regimes cash flows and their financial indicators were calculated and stored for analysis.

Output variables

Output variables are the simulation's results, and their analysis provide support to the forest manager's decision-making. The following financial viability indicators were the output variables: Equivalent Annual Annuity (EAA), Internal Rate of Return (IRR) and Average Production Cost (APC), for each of the 20 regimes, whose equations can be found on Rezende & Oliveira (2013). The maximum value of each financial indicator in each simulation, as well as their corresponding management regime, were included as output variables of the model.

Simulation and data analysis

The Monte Carlo method was implemented in a @EXCEL spreadsheet, with @Risk software add-in. A simulation convergence test was carried out, with 1% tolerance on quartile 75 and significance level of 99% for all output variables simultaneously, to evaluate the number of interactions needed for output variables distribution convergence, which was achieved with 18,900 interactions. A conservative approach was applied, running 100,000 simulations to obtain a more reliable database to analyse.

The GGPlot2 package in the R Studio software (RStudio, 2017; Wickham, 2009) was used for graphic generation.

RESULTS AND DISCUSSION

Modal management regime feasibility analysis

The modal management regime (P07S07) proved to be feasible in all simulations, with an EAA greater than zero and reaching US \$414.07 ha⁻¹, US \$372.81 ha⁻¹ and US \$331.55 ha⁻¹ in second rotation productivity loss scenarios with loss of 0%, 15% and 30%, respectively (Figure 1a). The probability of such silvicultural regime financial returns of at least US \$143.27 ha⁻¹ to the small farmer are 81.77%, 65.83% and 46.72%, respectively. The Internal Rate of Return (IRR) achieved exceeded the MAR (3.8%) in all simulations, even in the worst second rotation productivity loss scenario (Figure 1b). Analysing Figure 1c, it is observed that the average production cost (APC)'s worst (highest) value (US \$14.05 st⁻¹) was lower than the minimum value of the price probability distribution (US \$14.33 st⁻¹), asserting the modal management regime financial feasibility in all scenarios and simulations.

The EAA average value obtained by the modal regime was US \$198.82 ha⁻¹.year⁻¹, US \$171.62 ha⁻¹ year⁻¹ and US \$144.41 ha⁻¹ year⁻¹ for scenarios with 0%, 15% and 30% second rotation productivity loss, respectively. The average IRR values were 16.69% per year, 15.87% per year and 14.95% per year; and the average APC, US \$12.46 st⁻¹, US \$12.73 st⁻¹ and US \$13.05 st⁻¹, respectively.

Figure 1. Probability density of modal financial indicators.

Economically optimal management regime alteration as a consequence from scenarios and risk variables value changes

Changes in silvicultural scenarios (productivity, health, quality of wood) and/or economic (prices of inputs, producers, land rent, etc.) may alter forest management regimes' profitability, also changing their profitability classification.

Aiming to achieve a better understanding of the optimal management regime choice due to price and productivity variations, all management regimes financial indicators were recalculated with each simulation. The optimal management regime for each indicator, as well as their values and the values of input variables were stored. Its frequency as optimal silvicultural regime was calculated and shown in Figure 2a, for all the second cut productivity loss scenarios analysed. Figure 2b shows areas where price and productivity combinations highlighted the respective optimal management regime.

Figure 2: Optimal regimes' frequency and occurrence area for the Equivalent Annual Annuity with cost of land (EAA).

In the first scenario (S-00%), the modal management regime (P7S7) was optimal for more than 50% of the evaluated price and productivity scenarios, especially those with high income (high productivity and / or price). As price or productivity decreases, the producer would maximize his financial return by initially postponing the second rotation harvesting age to eight years (P7S8), followed by postponement of the first rotation harvesting age to eight years (P8S8) in case of steeper productivity decrease.

On a scenario of 30% productivity loss in the second rotation (S-30%), optimal modal management regime was absent, since the second rotation would no longer be recommended. Producers would maximize their results by adopting single rotation management regimes (P7S0, P8S0 and P9S0), clear-cutting and re-establishing their forests at harvesting age. However, cycle duration reduction tendency at higher income scenarios still remains.

Intermediate productivity loss scenarios (S-15%) presents a wider range of optimal management regimes according to wood price and productivity combination values, including optimal silvicultural regime second rotation presence or absence. In high price scenarios (above US\$ 17.20 st^{-1}) and medium or high yields, second rotation execution would not bring the producer the maximum gain possible, with economically optimal management regimes being those without second rotation (P7S0 and P8S0). In other scenarios, the second rotation execution would increase producer's profit.

A silvicultural regime length reduction for lower gross revenue tendency also remains in this scenario, but the optimal strategy for two rotation management regime differs from the S-00% scenario since, as income decreases, the optimal management regime increase the first rotation harvesting age initially, followed by an increase on second rotation harvesting age. These results corroborate those found by Rodríguez & Díaz-Balteiro (2006), when analysing optimal management regime behaviour under risk conditions in a Brazilian eucalyptus plantation.

Figure 3 shows the optimal management regimes relative frequency and its respective price and productivity area considering the Internal Rate of Return (IRR).

Figure 3: Optimal management regimes relative frequency and occurrence area according to Internal Rate of Return (IRR).

Observation of Figures 3 and 4 shows that financial optimal management regimes under the EAA financial indicator were not the same as those under the IRR, in both duration and frequency. Due to family farmers' production system low investment levels

when compared to business production systems, the IRR value reaches numbers well above the reference MAR (Figure 1b). The incorporation of second rotation in all optimal management regimes and its length reduction (P6S6) to the lowest possible as the most frequent optimal strategy in all scenarios is another noticeable behaviour when analysing results (Figure 3). Income reductions also increase the optimal silvicultural regimes' length, though at less sensitive rates than those observed on EAA-based strategy. Such results highlight the importance of choosing the financial indicator wisely according to the decision-maker's objective, since adopting different indicators can lead to very different production strategies.

Average Cost of Production (ACP) allows to evaluate a project with minimum average cost, regardless of production scale (quantity) or investment duration (Rezende & Oliveira, 2013). Figure 4 shows the relative frequency and productivity levels at which optimal management regimes are chosen considering APC.

Figure 4: Optimal management regimes relative frequency and occurrence area according to Average Production Cost (APC).

A high frequency of a single management regime as optimal in each scenario is observed in Figure 4a. The most frequent optimal regime under second rotation productivity losses below 30% and medium to high productivity was P8S8 (Figure 4b). Second rotation strategy was no longer included in scenarios with a 30% second rotation productivity loss, and the most common regime becomes P9S0, being adopted in all but high productivity scenarios (Figure 4a).

The inclusion of the second rotation productivity loss in the analysis allows to show how the optimal management regime may differ due to decrease of second rotation productivity. Silva (2016) found productivity losses in eucalyptus clonal tests ranging from 36 to 78%, demonstrating the feasibility of such reduction on second rotation productivity.

Execution of second rotation might not be recommended in cases of high productivity loss, since savings from not executing a stand re-establishment could be less than the income losses due to second rotation lower production.

Decision-making flexibility has great value under investment uncertainties, especially when the decision presents irreversibility (Tee et al., 2010). The forest harvesting age decision after cutting, is irreversible. If it occurs at a low, unexpected price sale, the profit loss will also be irreversible.

Forest producers face wood price and productivity uncertainties and must bear the consequences of its variability. Therefore, being flexible in selecting a management regime is advantageous for forest project profitability. Under low prices at pre-selected harvesting age, producers delay in operation and waiting for better prices or decreasing their financial losses by changing management regime would be preferable. Similarly, if high prices are faced before the pre-set cut-off period, bringing forward harvesting age could be advised in order to take advantage of the market and increase profitability (Chaudhari et al., 2016). The same adjustment opportunities could arise related to a stand productivity increase or decrease compared to the expected productivity in conjunction with wood price.

Profit increase by moving from modal management regime to optimal

The small farmer financial gain (given by EAA) when moving from modal management regime to optimal in each economic and productive scenario is shown in Figure 5. Gain is null or small where the modal and optimal management regimes do not differ highly (S-00% scenario), although some gain could be achieved by adjusting the silvicultural regime to optimal. Frequency of the modal management regime as optimal greatly decreases (S-15%) or reaches zero (S-30%) as second rotation productivity loss increases. Significant gains could be achieved on such scenarios by changing the modal management regime to the optimal, especially when the second rotation is not recommended anymore.

Figure 5: EAA gain due to selecting the optimal management regime over the modal one.

Gain varies between second rotation productivity loss scenarios. When maintaining productivity at second rotation (S-00%), gains varied between 0.57 and 4.30 US\$ ha⁻¹ year⁻¹, the highest absolute gains occurred in low productivity and low and medium wood prices (P08S08). In scenarios of intermediate losses (S-15%), gains varied between 0.86 and 7.74 US\$ ha⁻¹ year⁻¹, and the highest gains occurred in situations of high prices and productivity (P7S0), though they also showed greater amplitude. On the second rotation 30% losses (S-30%), the second rotation was not recommended and gains from adopting the optimal management regime were

significantly higher than those achieved in the other two scenarios, ranging from 12.89 to 48.71 US\$ ha⁻¹ year⁻¹.

This work's results agree with those of Souza et al. (2001), concluding that higher productivity levels tend to bring forward eucalyptus stand harvesting age. The additional contribution of this work emphasizes that this bringing forward could occur by an increase in income, due to either productivity or wood price increase.

CONCLUSIONS

The modal production regime is viable in all scenarios and simulations performed with EAA higher than zero, IRR higher than the MAR and APC lower than the minimum price observed in the region. The producer can have increased returns if his management regime is adapted to the silvicultural and economic scenario rather than adhere to the modal management regime.

High income (price and/or productivity) situations reduce silvicultural regimes' length in optimal management regimes. Prices and/or productivity reductions increase silvicultural regimes' length when taking into consideration the EAA as a decision-making financial indicator.

Change in optimal management strategy due to income reduction fluctuates according to productivity losses in the second rotation. In the absence of second rotation productivity loss, the optimal strategy adoption increases the second rotation harvesting age, followed by an increase of the first rotation harvesting age. The opposite was observed when losses on second rotation were present.

If the second rotation faces productivity losses, it may be removed from the optimal production strategy. Second rotation is not recommended for all 30% productivity loss scenario situations, or 15% productivity loss high price situations.

Adopting optimal regimes allowed farmer's gains when compared to unconditional adoption of the modal management regime. These gains were higher in second cut productivity loss scenarios.

The results show the importance of flexibility of forest management regime to maximize this asset's value, increasing wealth generation potential per area unit over time. The farmers' end results will most likely differ from the cash flow predicted at initial planning in businesses such as forestry, where markets face constant changes and uncertainties, and lengthy duration projects. As new information emerges and uncertainties about the market, production and future cash flows are better understood, the farmer may rely on silviculture management selection flexibility as a valuable tool for increased profits in future opportunities or loss reduction.

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