FOREST SCIENCES (CIÊNCIAS FLORESTAIS)

Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.15, n.4, e8407, 2020
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v15i4a8407
Protocol 8407 - 29/03/2020 • Approved in 11/08/2020

Technical and economic viability of *Eucalyptus* sp. coppice for charcoal production

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ABSTRACT: The aim of this study was to compare the properties of wood and charcoal of *Eucalyptus* sp., from two silvicultural systems (replanting and coppicing), in addition to assessing the economic viability of both systems, through the financial indicators Net Present Value (NPV), Internal Rate of Return (IRR) and Payback. The study was carried out in a charcoal producing company, located in the municipality of Itamarandiba, Minas Gerais, Brazil. The results showed that the wood from the coppice system has a lower Mean Annual Increment and a higher heartwood/sapwood ratio, producing a more friable charcoal and with lower productivity compared to the replanting system. Regarding the economic analysis, both systems were economically viable, with an IRR greater than the discount rate and a positive NPV. Comparatively, the economic results of the coppice system were slightly better, presenting less vulnerability in the sensitivity analysis regarding fluctuations in the price of charcoal. The option for coppice may be interesting for the producer due to its lower financial expenditure and satisfactory economic results, although with lower product quality.

Key words: friability; heartwood/sapwood ratio; internal rate of return; net present value; regrowth

Viabilidade técnica e econômica da talhadia de *Eucalyptus* sp. para a produção de carvão vegetal

RESUMO: O objetivo deste estudo foi comparar as propriedades da madeira e do carvão vegetal de *Eucalyptus* sp., provenientes de dois sistemas silviculturais (replantio e talhadia), além de avaliar a viabilidade econômica de ambos os sistemas, por meio dos indicadores financeiros Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR) e *Payback*. O estudo foi realizado em uma empresa produtora de carvão vegetal, localizada no município de Itamarandiba, Minas Gerais, Brasil. Os resultados demonstraram que as madeiras provenientes do sistema de talhadia apresentaram menor incremento médio anual e maior relação cerne/alburno, produzindo um carvão mais friável e com menor produtividade em comparação ao sistema replantio. Em relação à análise econômica, ambos os sistemas foram viáveis economicamente, com TIR maior que a taxa de desconto e VPL positivo. Comparativamente, os resultados econômicos do sistema de talhadia foram um pouco melhores, apresentando menor vulnerabilidade na análise de sensibilidade quanto a flutuações do preço de carvão. A opção pela talhadia pode ser interessante para o produtor em função de seu menor dispêndio financeiro e dos resultados econômicos satisfatórios, embora com menor qualidade do produto madeireiro.

Palavras-chave: friabilidade, relação cerne/alburno; taxa interna de retorno; valor presente líquido; rebrota

Introduction

The forest-based activities in Brazil are fundamental for economic, social and environmental development (Ribeiro et al., 2018). In 2018, the reforestation area for industrial purposes was 7.83 million hectares, with products from these forests accounting for 6.9% of the country's industrial GDP. Such activities provided a large volume of jobs that directly and indirectly benefited approximately 3.8 million people (IBÁ, 2019). In addition, from an environmental point of view, forest production contributes to reducing pressure on native forests and their predatory exploitation, which helps to conserve the biodiversity of these ecosystems.

Eucalyptus is the main genus used to supply the Brazilian forestry sector, being this genus the most used to produce pulp and paper, charcoal and solid wood products. The rapid growth, the ability to adapt to different edafloclimatic conditions and high productivity, optimized by the constant development of silvicultural techniques and genetic improvement, justify its wide use (Carneiro et al., 2013). Another interesting advantage of eucalypts is its ability to emit shoots after being harvested. Such shoots can be conducted to form a new individual, using a set of silvicultural techniques called coppicing, which therefore dispenses the need to replant (Xavier et al., 2009).

Since the first plantations of the *Eucalyptus* genus in Brazil, the management of shoots in the second rotation of forests is a reality in the management of this culture. Although, in most cases, the implementation of this system causes a decrease in the productivity of the forest, this disadvantage can be minimized with the reduction of the expenses with replanting the area. In addition, since interventions in the environment are reduced, the negative impact of this activity on the soil is reduced (Cacau et al., 2008; Gonçalves et al., 2014). However, the effect of coppicing on the quality of the final wood product, such as charcoal, is still little studied.

Charcoal is a product obtained through the carbonization of wood. In this thermochemical conversion process, the wood is subjected to low heating rates, in a controlled oxygen atmosphere, with final temperatures varying between 300 to 500 °C. The product of greatest interest obtained in this process is charcoal, a solid material with a high concentration of carbon (Mohan et al., 2006; Pereira et al., 2013). In addition to the process variables, such as final carbonization temperature, heating and cooling rate, the quality of the charcoal is highly influenced by the quality of the wood (Chen et al., 2015; Figueiró et al., 2019; Ucar & Ozkan., 2008).

In order to compare replanting and coppicing systems, it is necessary to analyze the quality of the wood and the final product generated in both systems, as well as to evaluate the economic viability of these systems, in view of the lower financial expenditure that usually occurs in the coppicing system - because it is a system with reduced interventions. Thus, it is necessary to carry out an economic evaluation of these forest projects, together with a sensitivity analysis of the main risk variables (Oliveira et al., 2014; Ribeiro et al., 2020). From these analyzes, forest producers will be able to make a more efficient decision-making on whether or not to carry out this silvicultural procedure.

Thus, the aim of this study was to compare the properties of wood (heartwood/sapwood ratio, basic density, chemical composition, higher heating value) and charcoal (gravimetric yield, apparent density, friability, proximate analysis, higher heating value), from two silvicultural systems (replanting and coppicing), in addition to assessing the economic viability of both systems.

Materials and Methods

General characterization of the study area

The study was carried out in a charcoal producing company located in the municipality of Itamarandiba, Minas Gerais, Brazil. The wood and charcoal properties of a clone, hybrid of *Eucalyptus grandis* W. Hill ex Maiden x *Eucalyptus urophylla* S.T.Blake, at 7 years of age, from commercial plantations with 3 x 3 m spacing, that were subjected to two types of silvicultural practices, replanting and coppicing, were evaluated.

The soil where the plantations were located is characterized as dystrophic red latosol and typical dystrophic red-yellow latosol, with a clayey or very clayey texture, the topography being considered flat (plateau) (Pulrolnik et al., 2009; Henriques, 2012). The edaphoclimatic condition is of annual rainfall of 1000 to 1200 mm, average temperature of 20 to 22 °C, and the climate is classified as Cwa according to Koppen's classification, dry-winter humid subtropical climate (Alvares et al., 2013).

Data collection and analysis

To characterize wood and charcoal, from replanting and coppicing systems, the mean annual increment of trees, in addition to the properties of wood and charcoal, were analyzed. The wood variables determined were: heartwood/ sapwood ratio, basic density, chemical composition and higher heating value. For charcoal, in addition to gravimetric yield, the following properties were determined: apparent density, friability, proximate analysis, higher heating value.

For this, five trees from a coppice management and five trees from replanting, of average population diameter, were used, totaling ten trees. Those individuals who had visual defects and/or located on the borders of the area were discarded.

The volume of the trees was obtained from measurements of the diameter along the stem, from the cutting base to the minimum diameter of 7 cm. The formula proposed by Smalian was used, where the volume of each section of the tree was estimated, for later obtaining the total volume (Ribeiro et al., 2017). Then the average volume of trees harvested was multiplied by the number of trees per hectare. Thus, by dividing the volume of wood per hectare (m^3 ha^{-1}) by age (years), the mean annual increment (MAI) was obtained.

The determination of the heartwood/sapwood ratio was performed with the aid of a magnifying glass with a ten-fold magnification, in which the transition region between heartwood and sapwood was identified. The total sapwood area was obtained, and by difference, in relation to the total disc area, the heartwood area was calculated.

The basic density of the wood was determined according to the water immersion method described by the standard ABNT NBR 11941 (ABNT, 2003).

The total extractives content was determined according to TAPPI 204 om-88 (TAPPI, 2001). The determination of soluble and insoluble lignin was carried out according to Gomide & Demuner (1986) and Goldschmid (1971), respectively. The total lignin content was obtained by adding the contents of insoluble lignin and soluble lignin. The ash content was determined according to the standard ABNT NBR 8112 (ABNT, 1986). The holocellulose content was calculated by subtracting the total lignin, extractive and ash contents from 100.

An IKA300 adiabatic calorimetric pump was used, according to the methodology described by ABNT NBR 8633 (ABNT, 1984), for the evaluation of the higher heating value of wood.

The carbonization of the wood was carried out in an electric muffle furnace, using 400g of oven-dried wood, at 103 ± 2 °C. The samples were inserted in a 0.003 m^3 metal container, located inside the muffle furnace. The temperature control was performed manually, in increments of 50 °C every 30 minutes, corresponding to a heating rate of 1.67 °C min^{-1}, until the final temperature of 450 °C, remaining stabilized in the latter by 60 minutes. After the end of carbonization, the gravimetric yield in charcoal was determined by gravimetry.

The apparent density of charcoal was determined according to Figueiredo et al. (2018). The charcoal friability was evaluated using a friabilometer, samples with known mass were rotated for 17 minutes at 35 rpm, weighed, and the percentage of mass loss calculated.

The volatile matter and ash contents in charcoal were determined according to ABNT NBR 8112 (ABNT, 1986). The fixed carbon content was calculated by subtracting the contents of volatile matter and ash from 100. The higher heating value was determined using an IKA300 adiabatic calorimetric pump, according to the methodology described by ABNT NBR 8633 (ABNT, 1984).

The data for the wood and charcoal variables, from the coppice and replanting systems, were subjected to the Lilliefors test for normality, and the Cochran test for homogeneity of variances. Subsequently, the results were subjected to analysis of variance (F test, $p < 0.05$). For this, the statistical analysis software R (R Core Team, 2018) was used.

Economic evaluation of forest projects

To develop a comparative economic analysis between forestry projects, these were called projects A - replanting and B - coppicing. The Discounted Cash Flow (DCF) method was used, considering a 21-year planning horizon for each project. Thus, two complete rotations of the regulated plantations were considered, in order to guarantee an annual flow of wood. In the regulated forests, a stand is implanted each year and from the moment the first stand is at the harvesting point, a stand is harvested each year (Silva & Ribeiro, 2006).

The total area considered for each of the projects was 60.69 hectares. To facilitate calculations of wood production, revenues and costs, the total area was divided into seven areas of identical size, resulting in 8.67 hectares to be implanted and, later, harvested per year. Thus, to work with a regulated forest, from the year 7 of the project and until the year 20, every year there will be a harvested area of 8.67 ha.

In the DCF methodology, the value of the project is measured by the amount of financial resources that will be generated in the future by the business, which is brought to present value to reflect the time and risk associated with the distribution (Martelanc et al., 2010). In this way, cash flow is projected from inflows (revenues) and outflows (costs).

The only financial input from the projects is the revenue from the sale of charcoal, which begins in year 7, with the production of the first area, its harvest and production of charcoal; and ends in year 20, with the harvest and production of charcoal from last area. The selling price of charcoal of R$ 600.00 ton^{-1} was considered, which is the average price practiced in the region, according to company data.

Outputs (costs) were divided into forest costs and financial costs. For project A (replanting) the forest costs were: planting implementation costs; maintenance; harvest and removal of the tree stumps; and carbonization cost (Table 1). For project B (coppicing), maintenance costs were the same, but implementation and harvesting costs were lower because they had fewer necessary activities (Table 2). All data were obtained from the forestry company.

The production cost of charcoal (carbonization) was obtained from the company, being estimated as a fixed cost of R$ 85.17 per ton of charcoal produced, including labor, machinery, and fuel necessary for the complete operation of carbonization. The costs of building the kilns were not included in these projects, since the company already has them.

The estimated financial costs were: economic cost of land; financial expenses with financing (which was simulated for each project), taxation and depreciation of the investment. The economic cost of land was calculated according to Silva et al. (2008), considering the project's interest rate of 10.00% per year and the land value in the region of R$ 4,000.00 $hectare^{-1}$ (Emater, 2019).

A financing with the Brazilian Development Bank (BNDES) of R$ 117,223.70 was simulated, the same amount for each project. This financing refers to the total amount of forest implantation (investment expenses) for all 60.69 hectares (that is, R$ 1,931.40 $hectare^{-1}$ implanted times the total amount of hectares of the project). These silvicultural expenses can be financed by the BNDES' Pronaf ECO financing line. The simulated conditions were: term of 10 years, grace period of 7 years, final financing rate of 4.60% per year and monthly payment periodicity via CAS - Constant Amortization System.

Taxation was considered to be 9.76% of the profit. This value was obtained in Imaña et al. (2015) for a forestry company producing charcoal in the state of Minas Gerais. This amount can be considered reduced since the state exempts charcoal producers from charging ICMS. An investment

Table 1. Forest costs for planting/replanting.

Costs - Planting / Replanting	Year	Unit	Amount	Value R$ Unit^{-1}	Cost R$ ha^{-1}
Soil preparation	1	h ha^{-1}	4.00	80.00	320.00
Subsoiling	1	h ha^{-1}	1.00	60.00	60.00
Gypsum	1	kg ha^{-1}	500.00	0.04	20.00
Chemical fertilizer	1	kg ha^{-1}	250.00	1.00	250.00
Herbicide	1	L ha^{-1}	5.00	18.00	90.00
Fertilizing	1	h ha^{-1}	5.00	30.00	150.00
Seedlings	1	un ha^{-1}	1,666.00	0.40	666.40
Planting	1	h ha^{-1}	6.50	30.00	195.00
Ant control	1	h ha^{-1}	6.00	30.00	180.00
Total cost of implementation					1,931.40
Ant control	2	h ha^{-1}	6.00	30.00	180.00
Manual weeding	2	h ha^{-1}	5.00	30.00	150.00
Manual weeding	3	h ha^{-1}	5.00	30.00	150.00
Administration and maintenance	1-7	-	7.00	11.00	77.00
Total cost of maintenance					557.00
Harvest	7	m^3	237.36	12.00	2,848.27
Chemical stump removal		h ha^{-1}	5.00	30.00	150.00
Total harvest + stump removal cost	-	-	-	-	2,998.27
Total cost per hectare					5,486.67

Table 2. Coppicing system costs.

Costs - Conduction	Year	Unit	Amount	Value R$ Unit^{-1}	Cost R$ ha^{-1}
Thinning	1	h ha^{-1}	5.00	30.00	150.00
Ant control	1	h ha^{-1}	6.00	30.00	180.00
Total cost of implementation					330.00
Ant control	2	h ha^{-1}	6.00	30.00	180.00
Manual weeding	2	h ha^{-1}	5.00	30.00	150.00
Manual weeding	3	h ha^{-1}	5.00	30.00	150.00
Administration and maintenance	1-7	-	7.00	11.00	77.00
Total cost of maintenance					557.00
Harvest	7	m^3	165.58	12.00	1,986.97
Total cost per hectare					2,873.97

depreciation rate of 10% per year was also considered. In addition, the project's discount rate (cost of capital) was set at 10% per year, which is common for silvicultural projects.

The financial indicators used to analyze the economic viability of the projects were the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback indicator. NPV (Equation 1) is the formula used to determine the present value of future payments discounted at a certain interest rate, less the cost of the initial investment.

$$\mathrm{NPV} = \sum_{j=0}^{n} \mathrm{Rj}\left(1+\mathrm{i}\right)^{-j} - \sum_{j=0}^{n} \mathrm{Cj}\left(1+\mathrm{i}\right)^{-j} \quad (1)$$

where: i = interest rate; Cj = cost at the end of the year j; Rj = revenue at the end of the year j; e, n = project duration in years.

The IRR (Equation 2) is the discount rate that equals the present value of revenues to the present value of costs, that is, it equals NPV to zero (Martelanc et al., 2010).

$$\sum_{j=0}^{n} \mathrm{Rj}\left(1+\mathrm{IRR}\right)^{-j} = \sum_{j=0}^{n} \mathrm{Cj}\left(1+\mathrm{IRR}\right)^{-j} \quad (2)$$

where: Cj = cost at the end of the year j; Rj = revenue at the end of the year j; e, n = project duration in years.

The Payback indicator is used to determine how long an investment takes to be repaid. Its calculation is done by accumulating the inflows and outflows, and determining the period in which there was a transition from a negative to a positive value, that is, the moment when everything that was invested is recovered (Martelanc et al., 2010).

Results and Discussion

Characterization of wood and charcoal

The heartwood/sapwood ratio and extractives content of the wood, in addition to friability and productivity in charcoal, showed significant differences between replanting and coppicing systems (Table 3).

The heartwood/sapwood ratio was higher in wood from the coppicing system, compared to wood from replanting. In species subjected to coppicing, a slower growth rate occurs, which in turn is accompanied by greater cell wall thickening, accumulation of extracts and cell inactivity, phenomena that characterize the heartwood formation (Kumar & Dhillon, 2014; Cherelli, 2015; Trugilho et al., 2019).

Table 3. Properties of wood and charcoal.

Properties	System		Probability
	Replanting	Coppicing	
Wood			
Mean annual increment (m³ ha⁻¹ year⁻¹)	34.60	26.88	0.045*
Heartwood / sapwood ratio (%)	0.66	0.89	0.020*
Basic density (kg m⁻³)	555.79	535.69	8.804
Extractive content (%)	3.47	6.54	0.046*
Lignin content (%)	30.04	29.06	25.577
Holocellulosis content (%)	66.49	64.40	0.709
Higher heating value (MJ kg⁻³)	19.13	19.33	1.766
Charcoal			
Gravimetric yield (%)	34.67	34.59	14.866
Apparent density (kg m⁻³)	341.85	372.73	1.851
Friability (%)	8.38	9.68	0.014*
Volatile matter content (%)	26.33	26.57	265.999
Ash content (%)	0.35	0.32	0.320
Fixed carbon content (%)	73.32	73.11	169.595
Higher heating value (MJ kg⁻³)	30.14	31.12	16.602

Legend: * Significant at 5% probability, by F test.

Thus, when the objective is the production of charcoal, a greater heartwood/sapwood ratio influences the wood drying process, either in the field or during carbonization. The heartwood, due to its low permeability, can hinder the release of water vapor during the drying of the wood, which can cause ruptures in parenchymal cells, resulting in a more friable charcoal (Costa et al., 2016). Thus, a greater heartwood/sapwood ratio, as observed in wood from the coppicing system, causes an increase in the friability of charcoal.

The extractives content is related to the heartwood formation process. Thus, woods that have a higher proportion of heartwood, such as those from the coppicing system, have a higher extractive content. The influence of extractives on the quality of charcoal will depend on the chemical nature of these components. Extractives of phenolic origin, for example, can contribute to the increase in the calorific value of wood and charcoal, in addition to the gravimetric yield in charcoal (Frederico, 2009).

The friability of charcoal refers to the tendency of this material to form fines when subjected to abrasive forces and mechanical shocks. The fines content is characterized as the residual fraction of charcoal, which although it can be used as supplementary fuel in the blast furnace, has as a consequence economic losses in the production of the product of greater added value, charcoal (Cardoso, 2010). The greater friability of the charcoal in the wood from the coppicing system, as well as the extractive content, is attributed to the greater heartwood/sapwood ratio presented in the wood from this silvicultural system.

The lignin content of the wood did not show any significant difference between materials from the coppice and replanting. Lignin has a high resistance to thermal degradation, due to the presence of a greater number of C-C and C=C bonds in its structure, in addition to having a high percentage of elemental carbon and low oxygen content, when compared to holocelluloses (Haykiri-Acma et al., 2010). Therefore, this property is directly correlated with the higher heating value of the wood, in addition to the gravimetric yield, proximate analysis and higher heating value of the charcoal (Carneiro et al., 2017), which justifies not observing significant differences for these properties.

Wood and charcoal production

The mean annual increment in the coppicing system, compared to the replanting system, showed lower values (Table 4). This reduction may be related, mainly, to the number of shoots conducted by stem and the reduction of vegetative vigor. Plants originating from shoots have a lower vegetative vigor than plants originating from replanting, which can compromise the growth and development of the tree (Stape et al., 2010).

The evaluation of the mean annual increment (MAI) is essential in forestry projects, as in the case of the charcoal sector, since lower values of MAI, are associated with the production of a lower volume of wood per hectare, in a given period, which affects the profitability of the activity.

From the productivity of 34.60 m³ ha⁻¹ year⁻¹, the cutting cycle of 7 years and the mortality rate of 2.00%, production in 7 years reached 2,058.00 m³ to 8.67 ha. This volume of wood was obtained for the 1st cycle of projects A and B, and for the second cycle of project A (replanting). In project B, the coppicing system led to lower productivity in the 2nd cycle, of 26.88 m³ ha⁻¹ year⁻¹, with a mortality rate of 12.00%, resulting in 1,435.67 m³ of wood production.

Charcoal productivity is the result of the interaction between wood production and its gravimetric yield. Therefore, when analyzing wood from the coppicing system, despite showing the same gravimetric yield as those from replanting, it presented materials with lower MAI and greater friability of charcoal, which justifies this decrease in productivity (t ha⁻¹) of charcoal.

Evaluating the production of charcoal, given the capacity of the kiln of 140 m³ of wood, it is possible to carry out 14

Table 4. Wood and charcoal production.

Production data	Unit	Replanting	Coppicing
Mean annual increment	m³ ha⁻¹ year⁻¹	34.60	26.88
Wood volume	m³ area⁻¹	2,058.00	2,058.00
Productivity	t ha⁻¹	42.75	31.49
Previewed batches per year	batches year⁻¹	14	10
Production of charcoal per batch	t batch⁻¹	27.12	26.06
Charcoal production per year	t year⁻¹	379.68	260.00
Loss with the friability of charcoal (fines)	%/year	8.38	9.68
Charcoal production per year (final)	t year⁻¹	347.86	235.37

batches year^{-1} for the annual wood volume of the 1st cycle of projects A and B. With the volume of the coppicing (2nd cycle) it is possible to make 10 batches per year. In view of the production of charcoal by batch of 27.12 tons and the loss of friability with fines, there was a production of charcoal of 347.86 tons year^{-1} for the 1st and 2nd cycles of project A and 1st cycle of project B, and 235.37 tons year^{-1} for the 2nd cycle of project B (Table 4).

Economic viability analysis

Table 5 shows the economic results obtained from the discounted cash flow analysis. It is observed that both projects obtained an IRR higher than the discount rate, and positive NPV, demonstrating the economic viability of both.

Comparatively, although the NPV of the replanting system was higher in all discount rate scenarios, the coppicing system obtained a higher IRR and lower payback than replanting, which demonstrates its greater viability and shorter term for reimbursement of the investment, even if the difference was small.

Although the economic results are very close, considering the IRR and Payback, the project of the coppicing system can be considered more viable. In other words, even if starting from lower forest productivity, and consequently, lower production of charcoal, its revenue still managed to pay the total costs, the financing and still generate profit. Its greater viability also occurred due to the fact that its costs per hectare are lower, since fewer interventions are required in this silvicultural system. With reduced implementation costs, compared to replanting, coppicing can bring greater financial flexibility to the forest producer who has less resources.

It is important to note that the two projects obtained positive net profit from the seventh year, that is, from the first carbonization. This shows that the revenue from the sale of charcoal has been robust in all years and has managed to pay for the costs of the projects.

Table 5. Results of the economic analysis on a 21-year planning horizon.

Data	Unit	Replanting	Coppicing
NPV (8.0%)	R$ thousand	407.96	375.60
NPV (10.0%)	R$ thousand	304.93	285.99
NPV (12.0%)	R$ thousand	228.73	218.55
IRR	%	35.6	37.5
Payback	Years	8	7

For the sensitivity analysis of scenarios, two variables of significant sensitivity to economic results were identified: the sale price of charcoal and the productivity of wood.

The tables below show the sensitivity of the NPV (in R$ thousand) for each project in relation to changes in the sale price of charcoal (R$ t^{-1}) and in wood productivity (m^3 ha^{-1} year^{-1}) .

Table 6 shows that the NPV of the replanting system is positive in all scenarios, even with price and productivity below that considered in this work, taking as a base scenario the productivity of 34.60 m^3 ha^{-1} year^{-1} and the price of R$ 600.00 t^{-1}.

As seen for the replanting project, in the coppice scenario (Table 7), positive results are observed in all variations in the price of charcoal and wood productivity, based on the productivity of 26.88 m^3 ha^{-1} year^{-1} and sales price of R $ 600.00 t^{-1}.

When comparing the two systems in these sensitivity scenarios, the following is observed: i) in the scenarios of lower productivity and reduced sales price of charcoal (less than or equal to R$ 450.00 per ton), the coppicing system obtained highest NPV; ii) this means that this system is less vulnerable to fluctuations in these variables than the replanting, which requires more investments for its implementation; iii) this type of analysis is essential for the producer to visualize the risks of his investment in the face of technical changes, such as productivity, and of the market, such as the selling price of charcoal.

Therefore, after evaluating the technical and economic results, this work considers the following: if the producer takes into account only the quality of wood and charcoal, the option for replanting would be more interesting, since the producer will be able to deliver a final product with better quality for the consumer.

If the producer decides on a system with less relative risk in the face of market fluctuations, the coppicing system may be more interesting, due to its lower financial expenditure and satisfactory economic results, even in adverse scenarios, such as the reduced price of charcoal and lower productivity.

Table 6. NPV sensitivity analysis (10.00%) of the replanting project.

NPV (R$ thousand)		Productivity (m^3 ha^{-1} year^{-1})								
		26.60	28.60	30.60	32.60	34.60	36.60	38.60	40.60	42.60
Charcoal price (R$ t^{-1})	400.00	3.69	23.02	39.82	54.56	67.60	79.21	89.62	99.01	107.51
	450.00	63.02	82.35	99.16	113.90	126.93	138.55	148.96	158.34	166.84
	500.00	122.36	141.69	158.49	173.23	186.27	197.88	208.29	217.67	226.18
	550.00	181.69	201.02	217.82	232.56	245.60	257.21	267.62	277.01	285.51
	600.00	241.02	260.35	277.16	291.90	304.93	316.55	326.96	336.34	344.84
	650.00	300.36	319.69	336.49	351.23	364.27	375.88	386.29	395.67	404.18
	700.00	359.69	379.02	395.82	410.56	423.60	435.21	445.62	455.01	463.51
	750.00	419.02	438.35	455.16	469.90	482.94	494.55	504.96	514.34	522.84
	800.00	478.36	497.69	514.49	529.23	542.27	553.88	564.29	573.67	582.18

Table 7. NPV sensitivity analysis (10.00%) of coppicing project.

NPV (R$ thousand)		Productivity (m³ ha⁻¹ year⁻¹)								
		18.88	20.88	22.88	24.88	26.88	28.88	30.88	32.88	34.88
Charcoal price (R$ t⁻¹)	400.00	55.96	54.48	61.21	67.95	74.69	81.42	79.94	86.68	93.42
	450.00	104.70	103.22	111.32	119.42	127.51	135.61	134.13	142.23	150.33
	500.00	153.44	151.96	161.42	170.88	180.34	189.80	188.32	197.78	207.24
	550.00	202.19	200.70	211.53	222.35	233.17	243.99	242.51	253.33	264.15
	600.00	250.93	249.45	261.63	273.81	285.99	298.18	296.69	308.88	321.06
	650.00	299.67	298.19	311.73	325.28	338.82	352.37	350.88	364.43	377.97
	700.00	348.41	346.93	361.84	376.74	391.65	406.55	405.07	419.98	434.88
	750.00	397.16	395.67	411.94	428.21	444.48	460.74	459.26	475.53	491.79
	800.00	445.90	444.42	462.04	479.67	497.30	514.93	513.45	531.08	548.71

Conclusion

The wood from the silvicultural system of coppicing has a higher heartwood/sapwood ratio, which resulted in a charcoal of greater friability, when compared to the replanting system. In addition, wood from coppicing showed a lower mean annual increment, which directly impacted its productivity in charcoal.

The replanting and coppicing systems were economically viable, with IRRs higher than the discount rate and positive NPV. In the comparison between the two, the coppicing system obtained slightly better economic results, with lower payback, that is, shorter term for reimbursement of the investment and higher IRR. Thus, even with lower productivity and quality of wood, which negatively impacts the charcoal produced, this system has led to more satisfactory economic results, in addition to being less vulnerable in situations of low charcoal prices. Therefore, this system becomes an interesting option economically for the forest and charcoal producer.

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