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Scientific Article

Economic viability of a silvopastoral system with and without the inclusion of carbon credits

Viabilidade econômica de um sistema silvipastoril com e sem a inclusão de crédito de carbono

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ABSTRACT - This study analyzes the economic viability of exotic and native caatinga forest species grown in silvopastoral systems, combined with the Guinea grass forage crop, compared to monoculture forestry systems, using carbon credits as an alternative source of extra income, aiming for an economic return on the sale of standing timber for firewood production. The experiment was conducted at the Experimental Station of the Pernambuco Agricultural Research Institute (IPA) in Belém do São Francisco, located in the semi-arid region of the state of Pernambuco, in the Itaparica micro region. Four tree crops were chosen, two of which are native to the Caatinga biome: Angico (*Anadenanthera colubrina* var. Cebil) and Aroeira (*Myracrodruon urundeuva* Allemão), and two exotic eucalyptus clones, *E. urophylla* x *E. tereticornis*. Guinea grass (*Panicum maximum* Jacq) was chosen as the forage. The intercropping of Guinea grass with the two eucalyptus clones proved to be economically viable in all the economic parameters analyzed, and this is the most suitable for marketing standing wood for firewood production. It is not economically advisable to sell the standing wood for firewood production in the monoculture and silvopastoral systems with the native species (Angico and Aroeira) at 96 months of age due to the system's economic unfeasibility. By adding the possibility of financial credit through the atmospheric carbon sequestered by the trees, it is possible to make all the costs of forestry crops in silvopastoral and monoculture systems economically viable.

Keywords: Agroforestry systems. *Eucalyptus*. Guinea grass. Carbon Market. Spacing.

RESUMO - O trabalho analisa a viabilidade econômica de essências florestais, exóticas e nativas da caatinga, cultivadas em sistemas silvipastoris, consorciados a cultura forrageira do capim Tanzânia, comparados aos de monocultivo florestal, utilizando-se do crédito de carbono como alternativa de renda extra, visando retorno econômico na venda da madeira em pé para produção de lenha. O experimento foi conduzido na estação Experimental do Pernambuco Agricultural Research Institute (IPA), no município de Belém do São Francisco, localizado na região Semiárida do estado de Pernambuco, Microrregião de Itaparica. Foram escolhidos quatro cultivos arbóreos, sendo eles dois nativos do bioma Caatinga: o Angico (*Anadenanthera colubrina* var. Cebil), a Aroeira (*Myracrodruon urundeuva* Allemão), e dois clones exóticos de eucalipto, *E. urophylla* x *E. tereticornis*. Em relação a forrageira, foi escolhido o capim Tanzânia (*Panicum maximum* Jacq). Os consórcios agrícolas do capim Tanzânia, com os dois clones de eucaliptos, apresentaram-se viáveis economicamente em todos os parâmetros econômicos analisados, sendo esse o mais indicado na comercialização da madeira em pé para produção de lenha. Não é recomendável economicamente a venda da madeira em pé para produção de lenhas no sistema de monocultivo e no silvipastoril com as espécies nativas do Angico e da Aroeira aos 96 meses de idade, devido a inviabilidade econômica do sistema. Agregando a possibilidade de crédito financeiro, mediante ao carbono atmosférico sequestrado pelas árvores, é possível viabilizar economicamente todos os custos dos cultivos florestais em sistemas silvipastoris e em monocultivo.

Palavras-chave: Sistemas agroflorestais. *Eucalyptus*. Capim Tanzânia. Mercado de carbono. Espaçamento.

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INTRODUCTION

Brazil northeastern region has heterogeneous soil and climate characteristics that allow for different forms of land use for agricultural production and its various purposes. Covering an area of 13% of the national territory, this region has serious problems regarding the sustainability of its agricultural production systems through conventional agriculture and the exploitation of arboreal vegetation to obtain timber products (OLIVEIRA, et al., 2015). Faced with this problem, environmental, social, and economic alternatives are extremely important. Among the alternatives available to producers in the northeast are agroforestry systems (AFSs).

Agroforestry systems refer to the use of land and the management of natural resources through the insertion of native or exotic woody species (trees and/or shrubs) associated with crops and/or fodder, simultaneously or sequentially in the same area (NAIR, 1993).

Unlike traditional monocultures, which, depending on how they are managed, can cause serious problems for the soil and the entire biotic and abiotic system, AFSs can be a more environmentally friendly agricultural production option. In addition, AFSs can generate extra income by providing services and consumer goods, ensuring the efficiency of the production unit, thus making it possible to obtain viable solutions to the various socio-economic problems commonly found in resource-poor regions (GEMIM; SILVA, 2017).

However, like any agricultural or forestry activity, agroforestry systems tend to run serious risks when used without technical knowledge or proper planning in their implementation and management since it is an activity that can generate doubts about how to obtain a greater financial return, but with the lowest possible probability of loss (PARRON et al., 2015).

When analyzing economic viability, all possible means of verifying whether the intrinsic revenues obtained by a given agroforestry investment project outweigh all the costs necessary for its implementation are evaluated, with the main objective being to decide whether or not a project can be conducted based on its economic results (REZENDE; OLIVEIRA, 2008). In this context, silvopastoral systems need to be well evaluated economically to define the best form of production (forestry + forage) in their income diversification, always respecting the local and intrinsic characteristics of the environment.

Among the various economic possibilities in the alternation of income included in silvopastoral projects, their aptitude for obtaining extra income stands out by creating carbon credits utilizing intercropped trees (OLIVEIRA et al., 2021). This promising alternative is based on the great capacity of trees to absorb atmospheric CO_2, thus reducing its adverse effects on the environment (ARAÚJO et al., 2018). This possibility, inserted in silvopastoral stands, can promote changes in the environmental conception of producers, making them a key player in issues related to reducing global warming (GOMES et al., 2021).

This study aims to analyze the economic viability of exotic and native caatinga forest species grown in silvopastoral systems, combined with the forage crop Guinea grass, compared to monoculture forestry, using carbon credits as an alternative source of extra income, aiming for an economic return on the estimated sale of standing timber for firewood production in the microregion of Itaparica, Pernambuco.

MATERIAL AND METHODS

Study area and description of the experiment

The experiment was conducted in an area of 5.6 hectares at the Experimental Station of the Pernambuco Agricultural Research Institute (IPA), in Belém do São Francisco, at 08º45'14" S and 38º57'57" W, with an altitude of 305 meters, in the semi-arid region of the state of Pernambuco, Microregion of Itaparica, where monoculture of different crops predominates, including onions and corn.

Four tree crops were chosen, two of them are native to the Caatinga biome: Angico (*Anadenanthera colubrina* var. Cebil) and Aroeira (*Myracrodruon urundeuva* Allemão), and two exotic eucalyptus clones, *E. urophylla* x *E. tereticornis*, called clone MA 2001 and MA 2000, all planted in March 2014.

Regarding the choice of forage crop, the basic needs of local smallholders were considered. Guinea grass (*Panicum maximum* Jacq) was chosen as it is a drought-tolerant species that can be used for animal feed during severe periods of drought.

The definition of the AFS arrangement was developed as follows:

The plantations were established at two spacings: 4m x 2m for the tree species in intercropping with Guinea grass and 3m x 2m for the tree species in monoculture (Figure 1).

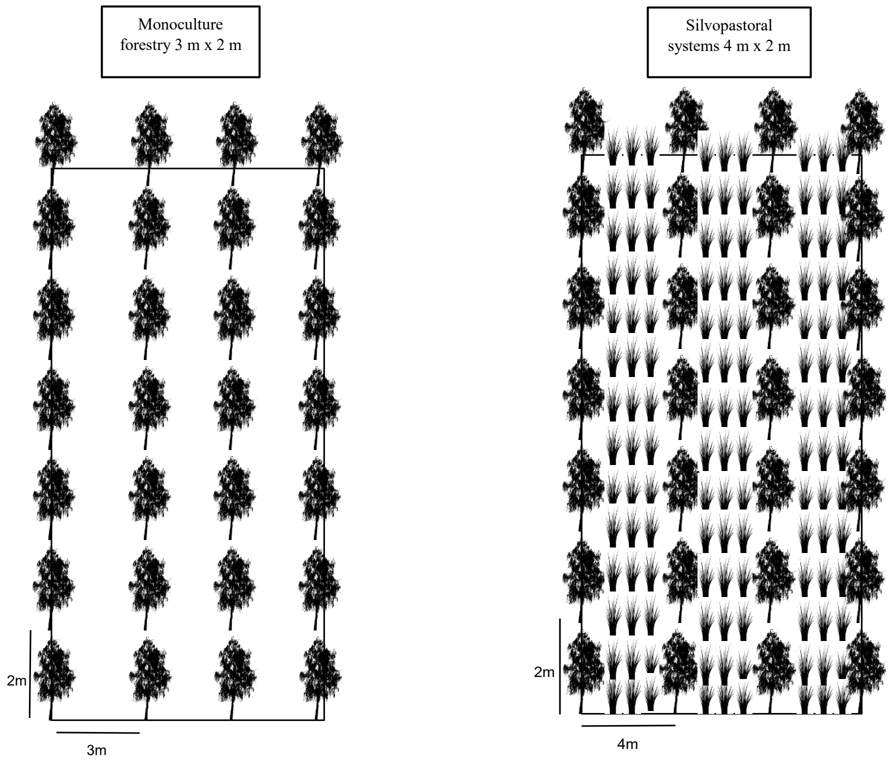

Figure 1. Arrangement and distribution of plant components in the production systems installed at the Experimental Station of the Pernambuco Agricultural Research Institute (IPA) in Belém do São Francisco, PE, Brazil.

The tree species were distributed in 128 plots with 28 plants/plot, 10 of which occupied the useful area.

For the sowing of Guinea grass intercropped between the forestry crop rows, the space between plants and rows was 0.5 m, totaling a plot of 14m x 16m (224 m^2).

Data collection

To quantify the yield of the AFSs forest and fodder crops, the procedure was as follows:

Guinea grass ($ton.ha^{-1}$): Cultivation period from 2015 to 2020, considering six annual harvests lasting 60 days/ harvest. The grass in the AFSs was cut at each harvest, selecting three samples randomly from each repetition, with a useful area of 1m². Within this useful area, all the grass leaves above 10 cm from the ground were cut off and then weighed to obtain their fresh weight. At the end of each cut, to assess the forage yield, the entire area of the experiment was lowered uniformly.

Wood volume (m^3. ha^{-1}): For each six months, from 2015 to 2022, the volume of the trees was obtained using the average form factor. For native species, the average form factor value of 0.871 was considered, as proposed for Caatinga species by Souza et al., (2016). For the eucalyptus clones (MA 2000 and MA 2001), the average form factors were used through rigorous cubing of samples of each eucalyptus clone in the experimental area, with the respective values (Clone MA 2000 at 3 m x 2 m spacing - 0.61; Clone MA 2000 at 4 m x 2 m spacing - 0.59; Clone MA 2001 at 3 m x 2 m spacing - 0.54; Clone MA 2001 at 4 m x 2 m spacing - 0.58).

$$V_t = g \times H \times ff \qquad g = \frac{\pi \times (DBH^2)}{4}$$

$$\longrightarrow$$

Where: V_t = Total volume; g = sectional area at 1.30m; H = Total tree height; DBH = Diameter at breast height at 1.30m from the ground.

Economic viability analysis

The financial evaluation of the systems was conducted as described below:

Net Present Value (NPV): An investment is economically viable when there is a positive difference between the revenues generated and their respective costs, updated at a certain rate of attractiveness (REZENDE; OLIVEIRA, 2008). As it is common for forestry projects to apply rates ranging from 5% to 10%, a discount rate of 9.17% was applied to this project, based on the average 5% per annum interest rate, referring to the PRONAF Floresta program, plus 4.17% for enterprise risk.

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

Rj = revenues in period j; Cj = costs in period j; i = discount rate; j= period of occurrence of Rj and Cj; n = duration of the project, in years, or number of periods.

Expected Land Value (ELV): represents the net present value of an area of bare land used for timber production based on perpetual net revenue. The activity is economically viable if the ELV is higher than the market value of the regional bare land (REZENDE; OLIVEIRA, 2008).

$$ELV = \frac{R_j}{(1+i)^t - 1}$$

Internal rate of return (IRR): This represents the annual rate of return of a given project with its invested capital and is indicated for verifying the average growth rate of a project (REZENDE; OLIVEIRA, 2008). The project is viable if the calculated IRR exceeds the attractiveness or discount rate.

$$\textstyle\sum_{j=1}^{n} R_j (1+i)^{-j} \qquad \sum_{j=1}^{n} C_j (1+i)^{-j} = 0$$

Benefit-Cost Ratio (BCR): Relates the present value of the benefits to the present value of the costs at a given rate of attractiveness. An economic project is economically viable if this ratio exceeds 1 (REZENDE; OLIVEIRA, 2008).

$$BCR = \frac{\sum_{j=1}^{n} R_j (1+i)^{-j}}{\sum_{j=1}^{n} C_j (1+i)^{-j}}$$

Values of costs and revenues in the implementation and conduct of the agroforestry project

Considering that the project aims to meet the demand for firewood in the region, the estimates of the price of the wood from the trees for conducting the economic analysis of the project were defined taking into account the monetary value in m^3 of standing wood, facilitating the reduction of extra costs related to cutting and transporting the wood, as follows:

For the eucalyptus clones, the value used was R$ 100.00 m^3 ha^{-1}

For the native species, Angico and Aroeira, the value used was R$ 57.00 m^3 ha^{-1}

The composition of the costs and yields of the implementation, administration, and production phases of the resources from the silvopastoral system, combined with Guinea grass and their respective monocultures, were established considering the specifications of each crop, based on the values practiced regionally. The implementation phase for monocultures and intercropped systems (Year 0) includes all the activities relating to purchasing seedlings, soil preparation, forest planting, cultivation, tree maintenance, land rental, and forage cultivation. The administration phase (Years 1 - 7) includes the periodic maintenance of the trees and forage in the intercropping system, and the production phase (Year 8) refers to the estimated sale of standing timber, thus reducing the costs of cutting and transporting the timber (Tables 1 and 2).

Table 1. Cash flow of tree species, implemented in a 3m x 2m monoculture, considering the sale of standing wood from the trees at 96 months.

Cultivation systems	Forest species	Year	Cost (R$.ha^{-1})	Revenue (R$.ha^{-1})	Balance (R$.ha^{-1})
Monoculture forestry 3m x 2m	Clone MA 2001	0	3906.53	-	- 3906.53
		1-7	850.00	-	-850.00
		8	-	16101.98	16101.98
	Clone MA 2000	0	3906.53	-	- 3906.53
		1-7	850.00	-	-850.00
		8	-	8341.53	8341.53
	Angico	0	7214.03		-7214.03
		1-7	850.00	-	-850.00
		8	-	3867.17	3867.17
	Aroeira	0	7214.03		-7214.03
		1-7	850.00	-	-850.00
		8	-	1184.92	1184.92

Table 2. Cash flow from tree species, implemented in a silvopastoral system with Guinea grass, 4m x 2m, considering the sale of standing wood from the trees at 96 months.

Cultivation systems	Forest species	Year	Cost (R$.ha^{-1})	Revenue (R$.ha^{-1})	Balance (R$.ha^{-1})
Silvipastoral system 4m x 2m	Clone MA 2001	0	4479.74	1542.00	-2937.74
		1-7	3248.45	2423.00	-825.45
		8	-	16101.98	16101.98
	Clone MA 2000	0	4479.74	1720.00	-2759.74
		1-7	2613.36	1804.66	-808.70
		8	-	11182.79	11182.79
	Angico	0	6961.31	1737.00	-5224.31
		1-7	3913.45	4471.34	557.89
		8	-	5459.89	5459.89
	Aroeira	0	6961.31	1582.00	-5379.31
		1-7	3913.45	6279.01	2365.56
		8	-	221.87	221.87

The estimated revenue from the sale of standing timber was based on a rotation period of 96 months, considering the initial year of the project in 2014.

To estimate the carbon sequestered from tree species, the woody biomass of standing trees was obtained by multiplying the specific weights of the wood by their respective average volumes observed at 96 months of age. The fixed carbon value of each tree is obtained by multiplying the woody biomass by the conversion factor of 0.5 (IMAÑA-ENCINAS et al., 2009). According to Gomes et al. (2021), to serve as parameters for estimating carbon credits, it is necessary to convert the total tree fixed carbon, multiplying its value by 3.67, to obtain the parameter of sequestered atmospheric CO_2eq. As the carbon market undergoes several variations in its market price, considering a very optimistic simulation, the commercialized value of the American carbon credit futures fund (CFI2Z2) was used, obtaining the average price for the year 2023 of approximately R$ 410.00 for each ton of carbon sequestered.

RESULTS AND DISCUSSIONS

Monoculture system 3m x 2m

Evaluating the forest monoculture at a spacing of 3m x 2m in the implementation phase, referring to year 0, which includes all activities related to the establishment of the forest stand, had a total cost of R$ 3906.53 ha^{-1}, for each eucalyptus clone and a total cost of R$ 7214.03 for each native species, consisting of the purchase of seedlings for 1 ha, with an additional purchase margin of 5%, considering possible mortalities in the stand. These values were based on the estimated unit value of seedlings for the eucalyptus clones of R$0.60/seedling and R$2.49/seedling for the native species. The rent for forestry and agroforestry cultivation for the eight years of production was based on the percentage of the region bare land value according to the project attractiveness rate, which was the regional value of R$ 3674.3 ha^{-1} and an applied attractiveness rate of 9.17% p.a.

The maintenance of the monoculture, which involved cleaning and pruning the trees, took place over the seven years of forest growth at a final cost of R$850.00 ha^{-1}. The revenue obtained for the MA 2001 clone, considering its volumetric production, was R$ 16101.98 ha^{-1}, with a final positive balance of R$ 11345.45 ha^{-1}. For the MA 2000 clone, the revenue obtained was R$ 8341.53 ha^{-1}, with a final balance of R$ 3585.01 ha^{-1}, given that the volumetric production for this clone, at 8 years, was 48.19% lower than the MA 2001 clone, directly influencing the total revenue.

With the native trees, considering their small size and the lower sale value of the standing wood, the profitability obtained for the Angico was R$ 3867.17 ha^{-1}. However, this value, considering the current age of 96 months, did not cover all the costs of implementing and maintaining the species in the project, resulting in a negative final balance of R$ -4196.86 ha^{-1} for an estimated volumetric yield of 67.85 m^3 ha^{-1}. This behavior was most noticeable with the Aroeira tree due to its small size and slow development. For this species, revenue of R$ 1184.92 ha^{-1} was obtained, reflecting the negative balance of R$ -6879.11 ha^{-1} for a yield of 20.79 m^3 ha^{-1}, considering the project analysis time of eight years.

It can be seen that when only the sale value of standing timber is taken into account, the profitability of the project is compromised, especially for native species. However, by adding an extra parameter to the investment project through increased revenue from monetizing the carbon sequestered by the forests, the final balance becomes positive for all species grown in monoculture. Table 3 shows the sequestered carbon stocks (CO_2eq) and their respective monetary values for the extra revenue, considering the average dollar exchange rate in 2022 of R$ 5.12 for every US$ 1.00. There was a significant average increase in the project final balance of more than 118,000 reais for the eucalyptus clones, with an average carbon sequestration of 141.27 ton.ha^{-1}. With the native species, the increase in the final balance in the monoculture was R$ 46,000, with an average carbon sequestration of 69.02 ton.ha^{-1}.

Table 3. Quantitative carbon parameters sequestered in a 3m x 2m forest monoculture, with their respective estimated financial revenue.

Cultivation systems	Forest species	$\overline{Vol}$ m^3/ha	P_{esp} (g.cm^3)	Total biomass (ton.ha^{-1})	C_{Total} (ton.ha^{-1})	CO_2eq (ton.ha^{-1})	Extra revenue (R$)	Balance with CO_2eq (R$)
Monoculture 3m x 2m	MA 2001	161.0	0.6	101.4	50.7	186.1	78215.7	89561.2
	MA 2000	83.4	0.6	52.5	26.2	96.4	40511.3	44096.3
	Angico	67.8	0.8	53.6	26.8	98.3	41330.7	37133.8
	Aroeira	20.8	1.0	21.8	10.9	40.0	16824.7	9945.6

P_{esp} = Average specific weight of forest species (SILVA et al., 2018; PAES et al., 2009); C_{Total} = Total carbon; CO_2eq = Carbon dioxide equivalent.

Based on all the flows generated over the 96 months of the project, corrected by the attractiveness rate of 9.17% p.a., economic indicators were obtained for the final assessment of the forestry enterprise, with and without the profit parameter for the estimated sale of sequestered carbon (Table 4).

Table 4. Economic parameters of forest species in a 3m x 2m monoculture, with and without the estimated carbon credit.

Methods	Monoculture tree species 3m x 2m							
	Clone MA 2001		Clone MA 2000		Angico		Aroeira	
	D/cc	C/cc	D/cc	C/cc	D/cc	C/cc	D/cc	C/cc
NPV (R$.ha^{-1}.year^{-1})	3447.8	42215.2	-398.7	19680.7	-5923.9	14561.6	-7253.3	1085.8
IRR (% p.a.)	17.6	47.6	7.84	35.7	-9	25	-23	11.0
BCR	1.9	11.8	0.90	6.0	0.18	3.02	-0.01	1.15
ELV (R$.ha^{-1})	10510.3	87376.3	2883.8	42696.0	- 8071.3	32546.2	-10707.2	5827.2

Where S/cc = economic parameters disregarding the carbon credit; C/cc = economic parameters considering the carbon credit.

Based on the economic parameters, disregarding the profit from carbon credits, it was found that the NPV for Clone MA 2001, at 96 months of age, showed a positive real gain of R$ 3447.76 ha^{-1}.year^{-1}, i.e., generating an appreciation of all the capital invested in year 0, making monoculture viable for this clone. This positive behavior was accompanied by the IRR value of 17.60%, above the attractiveness rate applied to the project, indicating a margin of safety and reliability of the investment for this respective clone since the economic parameter (IRR), its main function is to show the maximum acceptable limit for the use of interest rates, so that a given investment project is considered economically unviable (REZENDE; OLIVEIRA, 2008).

The cost-benefit ratio for the MA 2001 clone was R$1.88 for every R$1.00 invested, generating a significant gain in revenue. The ELV of R$ 10510.33 indicates the maximum limit that can be paid in the bare land value for the project to be considered viable, an estimate above the real value of the land practiced in the research region, making the investment positively viable. Based on all the results of the parameters obtained for the MA 2001 clone, it can be said that the monoculture of the respective species is economically acceptable for producing standing timber.

With the MA 2000 clone, however, even though it had a positive balance at 8 years, this value corrected to the current time, together with all the previous cash flows, does not pay for the capital invested in year 0, thus indicating a negative NPV of R$ -398.68 $ha^{-1}.year^{-1}$, making the project with this respective clone in the 3m x 2m monoculture unviable. This unfeasibility was accompanied by the other economic parameters, with a BCR of R$0.90 for every 1 real invested, an ELV of R$2,883.8, lower than the value of the bare land acceptable in the research, and a maximum IRR of 7.84%, below the attractiveness rate used in the project.

The unfeasibility of the MA 2000 clone was more prominent for native species in this form of cultivation. In all the economic parameters evaluated for Angico and Aroeira, the indication of the unfeasibility of the project was strengthened, indicating that the two species did not achieve sufficient development to pay back all the capital invested over time. This may be due to its slow to moderate growth genotypic characteristics, common for species native to semi-arid environments (FARIAS; MELO, 2020).

Weimann, Farias, and Deponti (2017), comparing the economic viability of eucalyptus grown in agroforestry systems and conventional plantations, found that the economic viability of monoculture systems was greater, corroborating in part the results obtained in this research. According to the authors, this viability of pure cultivation was mainly influenced by denser spacing, thus providing more individuals and a greater volume per area. However, Medeiros, et al. (2018) point out that trees in denser spacings, due to competition for nutrients, light, and water, can negatively compromise their production of leaves, branches, and shoots, and physiological damage can occur, thus affecting the quality of the economic commercialization of the final timber product.

When carbon credits are included in the financial analysis, there is a significant increase in all the economic parameters, making the monoculture system economically viable for all forest species, effectively remunerating all the costs of establishing and maintaining the stand. This viability of the system makes it possible to create an economic reserve to subsidize the maintenance of stands of forest species that have not reached their peak volumetric development, immediately favoring long cycle native species.

These results favor the possibility of creating different economic incentive mechanisms so that small producers can develop sustainable forestry practices with a guaranteed return on capital. According to Rezende et al. (2012) the carbon credit market is an opportunity for local and regional companies to offset their environmental damage by financing forestry projects that have the real capacity to absorb a significant amount of atmospheric carbon.

Silvopastoral system 4m x 2m

Considering the results generated from revenues from the silvopastoral system, with tree species intercropped with Guinea grass, it can be seen that in the system implementation phase, all tree species experienced reductions in their negative balances at this stage when compared to forestry cultivation alone. With the MA 2001 clone, compared to its respective 3m x 2m monoculture, this reduction was in the order of 24.80%. With the MA 2000 clone, the reduction was 29.36%.

This behavior was repeated with the native trees, with the Angico intercropped reducing its negative balance by 27.59% compared with its 3m x 2m monoculture. In the case of Aroeira, the combination of species yielded a reduction of 25.43% compared to its monoculture forest. Acceptable values are due to the immediate generation of income from the sale of forage at a time when the greatest expenditure of a forestry project occurs in its initial phase (KICHEL, et al., 2014).

In the maintenance stage of the silvopastoral system, the balances obtained in the intercropping with the eucalyptus clones were lower when compared to the native species since the production of the grass cultivated between the clones gradually decreased over the 4 years. With the MA 2001 clone, in this respective stage of the forestry investment, the balance obtained from the first to the seventh year was negative at R$ -825.45 ha^{-1}, while with the MA 2000 clone, its respective negative balance was R$ -808.70 ha^{-1}.

With native species, a positive balance can be generated by the seventh year of cultivation, making it possible to create a reserve flow by selling the grass produced directly, reducing the maintenance costs of the forestry system. This increase in income was more pronounced in the intercropping with Aroeira, generating a positive balance of R$ 2,365.56 ha^{-1} when the system was maintained until the seventh year. With Angico, this revenue generation with Guinea grass made it possible to create a smaller but positive balance of R$ 557.89 ha^{-1}.

In the final balance, at 96 months of the project, with the estimated revenue generated by the sale of the standing timber of the tree species added to their flows previously obtained in the system, only the intercropping with Aroeira had a negative final balance of R$ -2791.88 ha^{-1}, due to its relatively low volumetric yield of 3.89 m^3 ha^{-1}. The largest positive final balances were obtained with the eucalyptus clones, with R$ 12338.79 ha^{-1} for the MA 2001 clone, with an average yield of 172.67 m^3 ha^{-1}, and for the MA 2000 clone, with a positive final balance of R$ 7614.35 ha^{-1}, for a yield of 111.83 m^3 ha^{-1}. Angico was the only native species to show a positive final balance of R$ 793.47 ha^{-1} due to its estimated yield of 95.79 m^3 ha^{-1}.

When the extra revenue in the silvopastoral system is increased through the credit obtained for the sequestered carbon, there is a significant increase in all the final balances of the intercropped species, especially the eucalyptus clones, due to their greater volumetric development among the species (Table 5). On average, the amount of carbon sequestered in the silvopastoral system was 164.43 $ton.ha^{-1}$ of sequestered carbon for the two eucalyptus clones in the intercropping and 73.16 $ton.ha^{-1}$ for the native species. These values exceed those obtained in the monoculture forestry system, thus favoring the intercropping of species.

Table 5. Quantitative carbon parameters sequestered in a 4m x 2m silvopastoral system, with their respective estimated financial revenue.

Cultivation systems	Forest species	$\overline{Vol}$ m³/ha	P_{esp} (g.cm³)	Total biomass (ton.ha⁻¹)	C_{Total} (ton.ha⁻¹)	CO_2eq (ton.ha⁻¹)	Extra revenue (R$)	Balance c/ CO_2eq (R$)
Silvipastoral system 4m x 2m	MA 2001	172.7	0.6	108.8	54.4	199.6	83875.8	96214.6
	MA 2000	111.8	0.6	70.4	35.2	129.3	54314.8	61929.2
	Angico	95.8	0.8	75.7	37.8	138.8	58340.3	59133.8
	Aroeira	3.9	1.0	4.1	2.0	7.5	3147.3	355.4

P_{esp} = average specific weight of forest species (SILVA et al., 2018; PAES et al., 2009); C_{Total} = total carbon; CO_2eq = carbon dioxide equivalent.

Based on the respective cash flows of the intercropped tree species and considering the attractiveness rate applied to the project, all the economic parameters were obtained, considering the system evaluation with and without the financial attractiveness of the carbon credit (Table 6).

Table 6. Economic parameters of forest species in a 4m x 2m silvopastoral system, with and without the estimated carbon credit.

Methods	Tree species in silvopastoral systems 4m x 2m							
	Clone MA 2001		Clone MA 2000		Angico		Aroeira	
	D/cc	C/cc	D/cc	C/cc	D/cc	C/cc	D/cc	C/cc
NPV (R$.ha⁻¹.year⁻¹)	4533.0	46105.9	2267.6	29188.7	-1884.9	27031.3	-3381.1	-1821.1
IRR (% p.a.)	22.4	55.4	17.0	48.0	2.0	39.0	-19	1.0
BCR	2.5	16.7	1.8	11.6	0.6	6.2	0.4	0.7
ELV (R$.ha⁻¹)	12662.1	95090.5	8170.4	61547.9	-63.0	57270.5	-3029.5	63.5

D/cc = Economic parameters disregarding carbon credit; C/cc = Economic parameters considering carbon credit.

Evaluating the financial parameters of the silvopastoral system to check its economic viability at eight years of cultivation, it can be seen that only the eucalyptus clones obtained positive values in all the indicators proposed in this research, making it economically unviable to use native species in an intercropping with Guinea grass, intending to sell the standing timber at this respective age.

For the MA 2001 clone, the highest net present value was obtained among all the species, with a value of R$ 4533.02 ha⁻¹.year⁻¹, positively reversing all its corrected cash flows, generating wealth when opting for this type of intercropping. With an IRR of 22.44%, a BCR of 2.54 for every 1 real invested, and a maximum ELV attributed to this intercropping of R$ 12662.11 ha⁻¹, they indicate the acceptance of the economic viability of the option of using the respective clone in intercropping with the forage plant, showing its financial sustainability throughout the cultivation period in this respective association.

With the MA 2000 clone, the second best economically viable option was obtained for this type of intercropping, with NPV values of R$ 2267.62 ha⁻¹.year⁻¹, IRR of 17%, BCR of 1.82, and maximum ELV of R$ 8170.41 ha⁻¹, above the bare land value in the region, making the project economically viable.

Similar results were also found in research by Weimann, Farias, and Deponti (2017), Oliveira and Pagnussat (2019), and Cordeiro et al. (2014), in which they obtained positive values for economic indicators in the association of tree species in silvipastoral systems, indicating the effectiveness of this production model in increasing financial income.

When the possibility of extra income from sequestered carbon credits is added to the project, forest species' economic parameters increase dramatically, making intercropping projects viable. However, due to the low volumetric increment of the Aroeira in the intercropping, there was no significant increase in its economic parameters that could make the system viable at this age, thus requiring a longer cultivation period to provide a positive return on investment.

These results corroborate those obtained by Costa, et al. (2022), who found CO_2 capture values in the order of 176 and 191.9 ton.ha⁻¹ in eucalyptus forests in a 10-year-old ILPF system. These values were close to those found in this research for the silvopastoral system with eucalyptus, with average values for the two clones of 164.43 ton.ha⁻¹, showing the efficiency of this system in converting captured carbon sequestration into extra income for the forest investor.

Schettini et al. (2021), researching different forest arrangements in the silvopastoral system to verify the potential carbon sequestered by the trees, concluded that the larger spacings allowed for greater carbon storage between the individuals, thus confirming the results achieved in this research.

CONCLUSIONS

Based on the results obtained, we can conclude that:

The intercropping of Guinea grass with the two eucalyptus clones proved to be economically viable in all the economic parameters analyzed, making them the most suitable for marketing standing wood for firewood production;

It is not economically advisable to sell the standing wood for firewood production in the monoculture and silvopastoral systems with Angico and Aroeira (native species) at 96 months of age due to the system's economic unfeasibility;

Adding the possibility of financial credit, through the atmospheric carbon sequestered by the trees, it is possible to make all the costs of forestry crops in silvopastoral and monoculture systems economically viable, except for the Aroeira in the intercropping system, due to its low volumetric increment;

Government incentives for carbon credits in agroforestry projects in northeastern Brazil through regional development financing programs, such as the FNE of the Nordeste do Brasil Bank, can help increase regional investment and contribute to agricultural development, provided that the systems are economically and technically viable.

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