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Artigos

Breakeven price of CO_2 credits driving farmers to use the area to plant forest instead of grain

Preço de equilíbrio dos créditos de CO_2 levando os agricultores a usar a área para plantar florestas em vez de grãos

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ABSTRACT

Afforestation and reforestation were the challenges the farmer can seize to plant a culture that can capture more carbon than the amount emitted for cultivation. Assuming that the land was legally rented and owned, and part of an area that had not been obtained through recent deforestation, the main questions were: "why a farmer should have preferred to reserve the area to plant trees?"; and "How much did one ton of Carbon Dioxide [CO_2] have to be rewarded to buy this opportunity?" This work had the target to estimate which was the minimum price for carbon credit so that the farmer will plant a forest instead of using the soil for grain cultivation. Based on the analysis that economic aspects and profit were the main drivers considered by the farmer to decide how to use the soil in case the area was not classified as Legal Reserve or Permanent Protection Area, seeking the usage which maximized the value per hectare. Considering a eucalyptus commercial forest planted under the premises of the current study, results showed that a price of around 24 BRL per ton of CO_2 in 2021 is enough to turn it economically feasible. Business case had been estimated with and without profit coming from the commercial use of forest, and even assuming that no wood is cut and sold, the 2021 price of 40,48 BRL per ton of CO_2 can ensure more profit than grain production over 14 years timeframe, allowing the farmer to make money beyond the usual commercial use of a forest.

Keywords: Carbon offset; Soybeans; Eucalyptus; Carbon credit; Reforestation

RESUMO

Florestar e reflorestar foram os desafios que o agricultor pode enfrentar para plantar uma cultura capaz de capturar mais carbono do que a quantidade emitida para o cultivo. Partindo do pressuposto de que a terra era legalmente arrendada e própria, e parte de uma área que não havia sido obtida por meio de desmatamento recente, as principais questões eram: “por que um agricultor teria preferido reservar a área para plantar árvores?” e “Quanto uma tonelada de Dióxido de Carbono [CO_2] teve que ser recompensada para comprar esta oportunidade?” Este trabalho teve como objetivo estimar qual o preço mínimo do crédito de carbono para que o agricultor plante uma floresta ao invés de usar o solo para cultivo de grãos. Com base na análise, os aspectos econômicos e de lucro foram os principais direcionadores considerados pelo agricultor para decidir como usar o solo caso a área não fosse classificada como Reserva Legal ou Área de Proteção Permanente, buscando o uso que maximizasse o valor por hectare. Considerando uma floresta comercial de eucalipto plantada nas dependências do presente estudo, os resultados mostraram que um preço em torno de R$ 24 por tonelada de CO_2 em 2021 é suficiente para torná-la economicamente viável. O caso de negócios foi estimado com e sem lucro proveniente do uso comercial da floresta e, mesmo assumindo que nenhuma madeira seja cortada e vendida, o preço de 2021 de R$ 40,48 por tonelada de CO_2 pode garantir mais lucro do que a produção de grãos ao longo de 14 anos, permitindo ao agricultor ganhar dinheiro além do uso comercial usual de uma floresta.

Palavras-chave: Compensação de carbono; Soja; Eucalipto; Crédito de carbono; Reflorestamento

1 INTRODUCTION

Recently, global awareness of atmosphere pollution with higher levels of CO_2 (carbon dioxide) emission and its dramatic effects on climate change has gained strength. Over the last two decades, people, consumers, companies, and electoral pressure on governments have significantly increased their attention to reducing and compensating for Greenhouse Gases [GHG] emissions, especially CO2 (BRISTOW, 2007).

Most countries have set challenging emission-reduction targets under their national climate plans known as Nationally Determined Contributions [NDC], for example, European Union aims to reduce 55% in 2030 to 1990 levels, and to become climate neutral by 2050 (EUROPEAN COMMISSION, 2030). These targets have been deployed to all layers of the society and economic system, just recently, at United Nations [UN] Climate Change Conference (COP26) in Glasgow, more than 1000 private companies, following Environmental Social Governance [ESG] principles, have committed to achieving “net-zero” GHG emission by or even before mid of the century (STUART, 2021). According to research performed by consulting firm McKinsey in 2021, private companies are reallocating more than one trillion dollars for investments focused on sustainability and related strategies, products, and services.

Carbon credits are presented as a sustainability strategy and play a key role to reach emission-reduction targets, nowadays their relevance has definitively increased to 1997 when the Kyoto Protocol established tradable certificates representing the right to emit one metric ton of CO_2, which defined a framework for cooperation among countries and central UN mechanisms to trade credits from emission reduction through specific projects (KIZZIER; LEVIN; RAMBHAROS, 2019).

Even if important achievements have been reached, like double counting avoidance and guidance for a new (global) carbon market, many critics have been moved about the fact that: (i) just 2% of old credits will be scrapped resulting in keeping a huge amount of “poor quality” credits in the market; (ii) Glasgow rules neglect explicit guidelines for the voluntary market, private projects that are happening outside a country’s NDC are not adjusted in the country’s carbon budget (WORLD BANK, 2022). Robust rules still need to be established for this purpose, many actors operating in voluntary offset markets can actively contribute, driven by ESG (Environmental, Social, and Governance) values (APPUNN, 2021).

Among all activities and projects related to CO_2 offsets, forestry represents one of the most effective alternatives to sequester carbon and generate related CO_2 credits targeting the voluntary market as well, since trees naturally pull and store carbon out of the atmosphere (CARBON OFFSET GUIDE, 2021). When forestry is considered to offset CO2 emission, several strategies can be identified: (i) Afforestation: which consists in planting trees in a spot that previously didn’t have them, to fight environmental challenges; (ii) Reforestation: which consists in planting trees where forests have been clear cut or deforested, for example when the area had been previously used for other activities like agriculture and farming; (iii) Avoided Deforestation: has to do with the strategy to provide incentives to landowners to keep forests intact when they could otherwise clear land for agriculture and other activity (LIN; LIN, 2013; TENG; FAN-PENG; YUNG-HO, 2021).

Forests grow in most ecosystems in Brazil where climatic and soil conditions are characterized by huge diversity (SPELTZ; FERRAZ-ALMEIDA, 2021). Among the Brazilian biomes, the Cerrado is the second in terms of area after the amazon rainforest, representing more than 23% of the share and 2 million of Km^2. Cerrado, characterized by seasonal climate, extends into the central states of Brazil and is considered a rich savanna in biodiversity (COSTA; FONSECA; KÖRTING, 2015). The soil in Cerrado is quite poor and originally not suitable for agriculture, this has pushed scientists in studying deeply how to improve soil fertility, the techniques developed and applied in the last decades have transformed the region in a reference in terms of productivity for agriculture in Brazil (EMBRAPA, 2022; FERRAZ-ALMEIDA; DA MOTA, 2021). Cerrado is also the focus of critics related to deforestation, according to IPAM [Amazon Environmental Research Institute] in 15 years between 2000 and 2015 Cerrado lost a huge area of 236,000 km^2, even more than Amazon in the same period. Since the '70 Cerrado has represented the agricultural frontier in Brazil, transforming the society and the economics, and creating questionable situations with people who were living originally in the area.

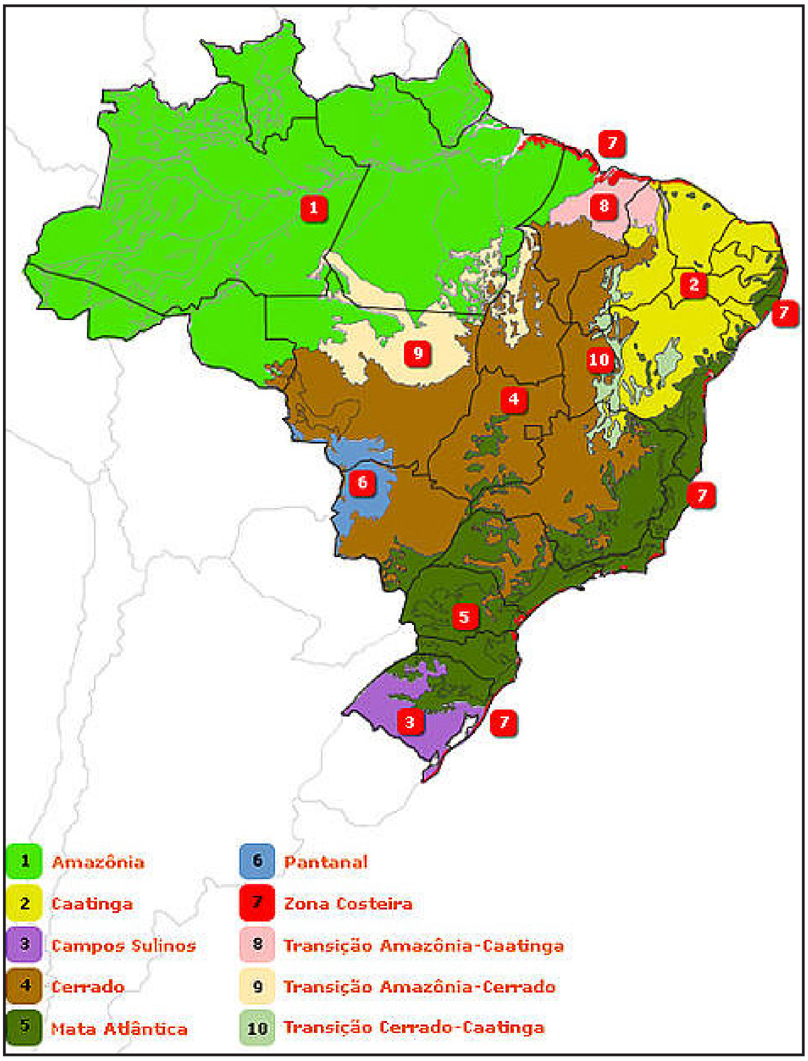
Afforestation and reforestation are presented as strategies to capture more carbon than the amount emitted for cultivation. Assuming that the land was legally rented and owned, and part of an area that had not been obtained through recent deforestation, the main question was: why a farmer should have preferred to reserve the area as forestry, and how much one ton of CO_2 had to be rewarded to offset the equivalent profit coming from a profitable land use like grain production? The study focused on the business case, to estimate which is the minimum price for carbon credit that a farmer will choose to plant forest instead of grains.

2 MATERIALS AND METHODS

2.1 Study characterization

The study was geographically focused on Cerrado Biome in Brazil, in the northwest of the Cerrado area, precisely in Sorriso, Mato Grosso (Latitude: 12°33’31” South, Longitude: 55°42’51” West; altitude: 386 m) (Figure 1). The region has a climate classified as Aw (tropical wet and dry or savanna climate), according to the Köppen-Geiger classification, with an average temperature of 24°C and an annual precipitation average of 2,250 mm.

Figure 1 – Brazilian biomes



Source: WWF (2023)

The study considered an area already free of forest for a long time, free from environmental limitations, which could be legally exploited by the farmer for agricultural activities. Typical described as a degraded area with pasture which was then converted for more rentable use. The analysis was concentrated on economic factors leading to an economic decision, in principle ethical and social aspects were not considered.

In the scenario, considered the carbon credits generated by a hectare of the planted exotic forest of Eucalyptus (Eucalyptus grandis), representing the most popular exotic tree species in Brazil. The profit coming from selling CO_2 credits is then added to the one generated by possible forestry activity evaluating four alternative scenarios: A two cycles lasting 7 years each, with the selective cut at the end of the first cycle, B same as A but with systematic cut, C 14 years cycle, D no cut. Scenario D ensures the preservation of CO_2 stored in the tree; the other scenarios (A, B, and C) need to be considered under the challenging premise that the future intended usage of the wood does not release the stored CO_2.

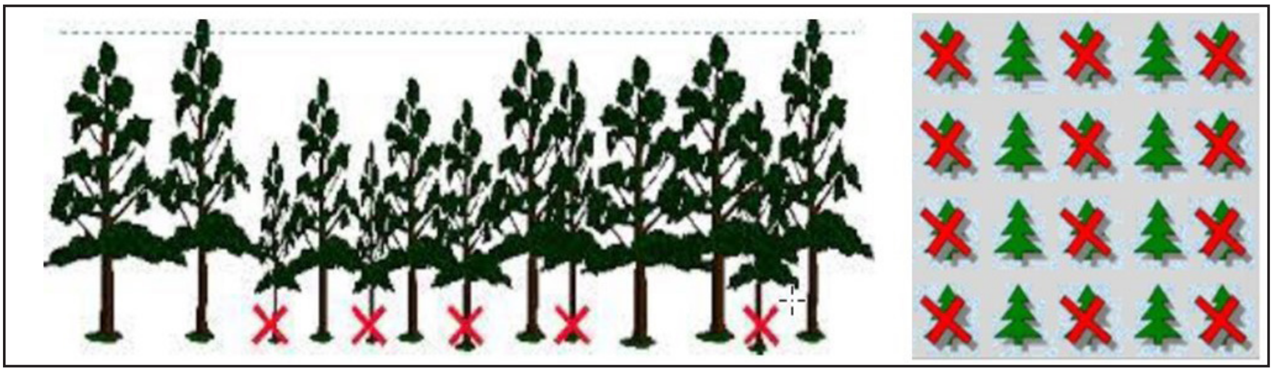
2.2 Forestry and crop scenarios

The first scenario A simulated trees planted at year 0, selective cut at year 7, and full cut at year 14. The selective cut is set on a minimum basal area of 10, bringing the number of trees per hectare from 1510 (year 7) to 266 (year 8). This strategy impacted negatively on Average Annual Increase [AAI] and maximized the size of each tree at the final cut (Figure 2).

The second scenario B consisted of trees planted at year 0, systematic cut at year 7, and full cut at year 14. A systematic cut is set to reduce the population to one-third in year 7, from 1510 to 499 trees per hectare. This strategy sacrificed the individual volume but maximizes the overall volume.

The third Scenario C simulated trees planted at year 0 and fully cut at year 14. This scenario maximized the overall volume of forest per hectare, but the small size of the trees usually allows a huge production of cellulose and small production of wood for the sawmill as reported in Table 1. The fourth scenario D was equivalent to the third one concerning the forest development, but no cut, and therefore no income from the forest was added.

Figure 2 – Scenario A (selective cut at year 7 and full cut at year 14) and Scenario B (systematic cut at year 7 and full cut at year 14) in Sorriso, Mato Grosso, Brazil



Source: Authors (2023)

Table 1 – Wood volume generated by each scenario and starting and ending tCO_2 price for Scenarios A, B, C, D, and D, but no cut and therefore no income from the forest) in Sorriso, Mato Grosso, Brazil

Scenarios	**Cut time (2021)**	**Overall Volume**	**Sawmill Wood type1**	**Sawmill Wood type2**	**Cellulose**	**Other**
				m^3		
Scenario A	7 years	259,4	0	14,3	222,6	22,5
	14 years	318,1	191,3	87,8	34,9	3,2
Scenario B	7 years	241,9	0,3	38,4	185,5	17,7
	14 years	339,6	63,5	169,6	98,3	8.0
Scenario C	14 years	611,1	26,3	217	343,3	24,3

Scenarios	**tCO2 price for each scenario simulated**	
	tCO_2 starting price (2007)	**tCO_2 ending price (2021)**
Scenario A	13,34 BRL	28,36 BRL
Scenario B	13,22 BRL	28,12 BRL
Scenario C	11,47 BRL	24,39 BRL
Scenario D	19,03 BRL	40,48 BRL

Source: Authors (2023)

In where: A is a selective cut at year 7 and full cut at year 14; B is a systematic cut at year 7 and full cut at year 14; C is a full cut at year 14; D is equivalent to the third one concerning the forest development.

In the crop scenario, considered the production of soybeans (1st harvest) and corn (2nd harvest) in the succession system (14 years from 2007 to 2021). This premise put the study into realistic conditions considering the combination of gross grain crops which was the mainstream.

2.3 Costs and CO2 credits

In this work, to improve matching between the forest growth model and environmental conditions in Brazil, it was used the tool SisEucaliptus available at Empresa Brasileira de Pesquisa Agropecuaria [EMBRAPA] (OLIVEIRA, 2021). SisEucaliptus was developed to monitor the weight of wood per hectare and growth rate with production in volume of wood (m^3) and carbon credits generated in volume (m^3/ha).

Premises of cost and revenue have been adopted to perform the estimation of the economic figures, specifically to calculate the value (profit per hectare) generated by 14 years of soybeans/corn production (2007-2021) in the same area.

The revenue for each scenario was considered according to the amount of specific final product (sawmill wood, cellulose, etc) and market price, where: net future value in 2021 was R$ 6.286,56 (scenario A, selective cut), R$ 6.078,11 (scenario B, systematic cut), and R$ 6.199,91 (scenario C, direct cut). The prices considered for forestry subproducts were, in 2014: R$ 26,83 m^3 (sawmill Wood1, large), R$ 20,12 m^3 (sawmill Wood1, medium), R$ 11,40 m^3 (cellulose), R$ 11,40 m^3 (other), and in 2021: R$ 40,00 m^3 (sawmill Wood1, large), R$ 30,00 m^3 (sawmill Wood1, medium), R$ 17,00 m^3 (cellulose), R$ 17,00 m^3 (other).

Scenarios A, B, and C were based on an economic point of view, under the hypothesis that cut wood is sold according to market prices at years 7 and 14 for scenarios A and B and at year 14 for the scenario C. Economics is scaled from one year to another by applying the inflation rate IPCA (consumer price index). Four forestry products were defined according to wood size and length are given in output by SISEucaliptus for each scenario.

The year zero (first year) included a cost of 2.000 BRL related to soil preparation before crop production a premise of this study was that the starting point was an unproductive area and possibly a degraded pasture. Assuming the soil preparation is done, the land is considered ready for commercial use a couple of years after for soybeans (2009) and three years after for corn (2010) (CONAB, 2022). Fixed costs, depreciation, and production factor remuneration (e.g., land) were considered just for soybeans since the land is in common.

The analysis added the contribution of profit generated yearly by carbon credits sold by the farmer according to the amount of CO_2 captured by the hectare of forest, considered as delta captured each year. This amount of money received was considered as pure profit, in addition to what was earnt through forestry traditional activity with the same hectare at the end of the cycle. Although the discussion about the pricing of voluntary carbon credits was ongoing for many years (REDD Monitor, 2014), this work was not considering how the voluntary credits are priced in the market, certified, intermediated, brokered, and taxed; the focus was on minimum net price paid to the farmer to get forestry competitive against gross grain cultivation.

The present study set the base price at the beginning of forest operation (2007), which leads the hectare to generate a profit over the 14 years equivalent to gross grain planting considered according to Equation (1).

$$p[x + 1] = p[x] + IPCA \tag{1}$$

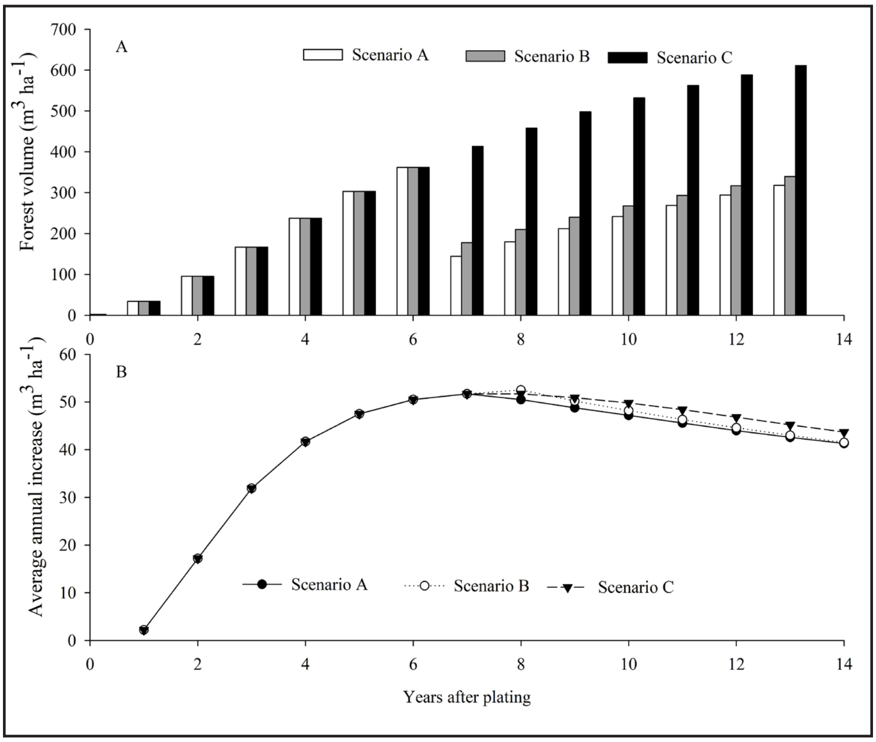
Where: p[x] was the net price for one tCO_2 paid in the year x to the farmer; (ii) p[0] was the price set at year zero (2007) to equal Net Value 2021 got with gross grain planting R$ 20.657,99.

3 RESULTS AND DISCUSSIONS

3.1 Forest growth and Carbon credits

Between 0 and 7 years, the forest growth was similar between scenarios A, B, and C with a production of 361.8 m^3 ha^{-1}. After the 7 years, in Scenario A and B, there was the respective cut selective and systematic with a volume of 144.5 and 178.0 m^3 ha^{-1} in the 8th year. In Scenario C, there was no cut with a total of forest produced of 611.1 m^3 ha^{-1}, which was higher than the final production in Scenario A (318.1 m^3 ha^{-1}) and B (339.6 m3 ha^{-1}), Figure 3A. The annual increase between the scenarios also was similar until the 7th year with an average of 51.7% with a posterior decrease in all scenarios and an average of 41.3%; 41.5%; and 43.7% in scenarios A, B, and C, respectively (Figure 3B). The forest growth in all scenarios is accorded with the literature (GONÇALVES; OLIVEIRA; CARVALHO; GOMIDE, 2017; CORRÊA; SOARES; ALVES; SOUZA; VIEIRA, 2020).

Figure 3 – Forest growth comparison over 14 years cycle and average annual increase in Scenarios A, B, and C, in Sorriso, Mato Grosso, Brazil



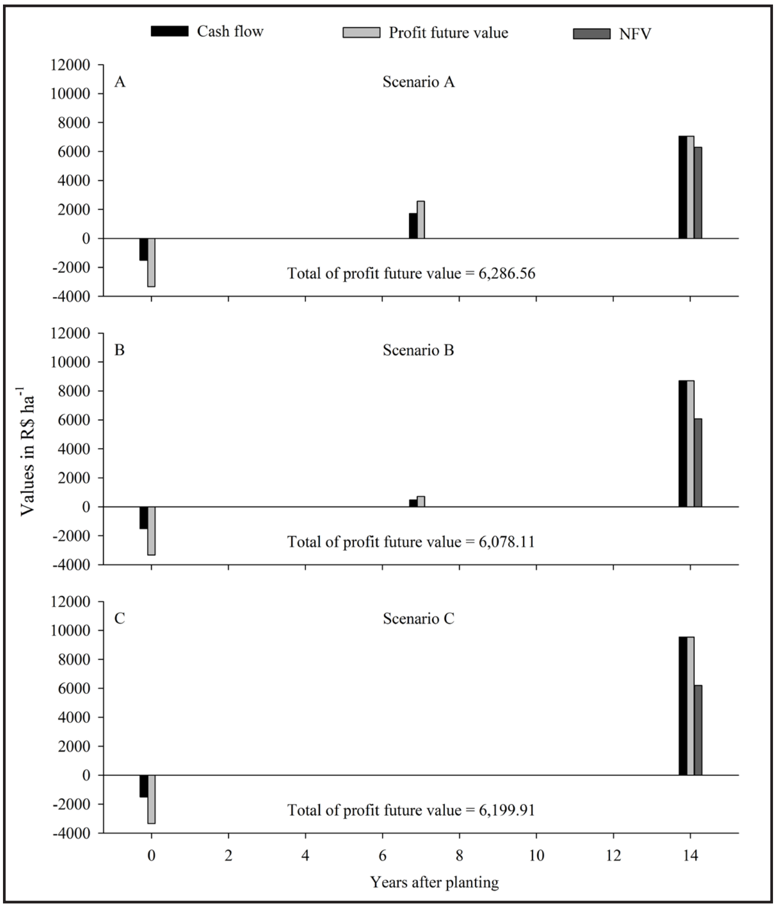
Source: Authors (2023)

In where: A is a selective cut at year 7 and full cut at year 14; B is a systematic cut at year 7 and full cut at year 14; C is a full cut at year 14; Scenario (d) was not considered since no wood is cut or sold.

When we compared the results of each strategy over 14 years, the 7th year cut impacted the overall volume and growth rate, putting the scenario of selective cut (a) as the less performant and scenario C without intermediate cut at the top. Scenario C was the one cumulating more wood volume along the cycle and with the highest Average Annual Increase, therefore it was expected that also more carbon is sequestered, and a higher amount of carbon credits can be generated, certified, and sold in the market.

In all scenarios, in the 0 year, there was a negative cash flow of R$ -1,500.00 ha^{-1} $year^{-1}$ caused by an operational cost of R$ -3333.50 ha^{-1} $year^{-1}$. While, in the 7th year in scenarios A and B, respectively, there was a positive cash flow of R$ 1,718.74 ha^{-1} $year^{-1}$ and R$ 472.70 ha^{-1} $year^{-1}$ caused by wood commercialization of R$ -2,562.25 ha^{-1} $year^{-1}$ and R$ 704.70 ha^{-1} $year^{-1}$ (Figures 4A and B).

Figure 4 – Cash flow (R$ ha^{-1}), profit future value (R$ ha^{-1}), NFV (R$ ha^{-1}) in Scenarios A, B, and C, in Sorriso, Mato Grosso, Brazil



Source: Authors (2023)

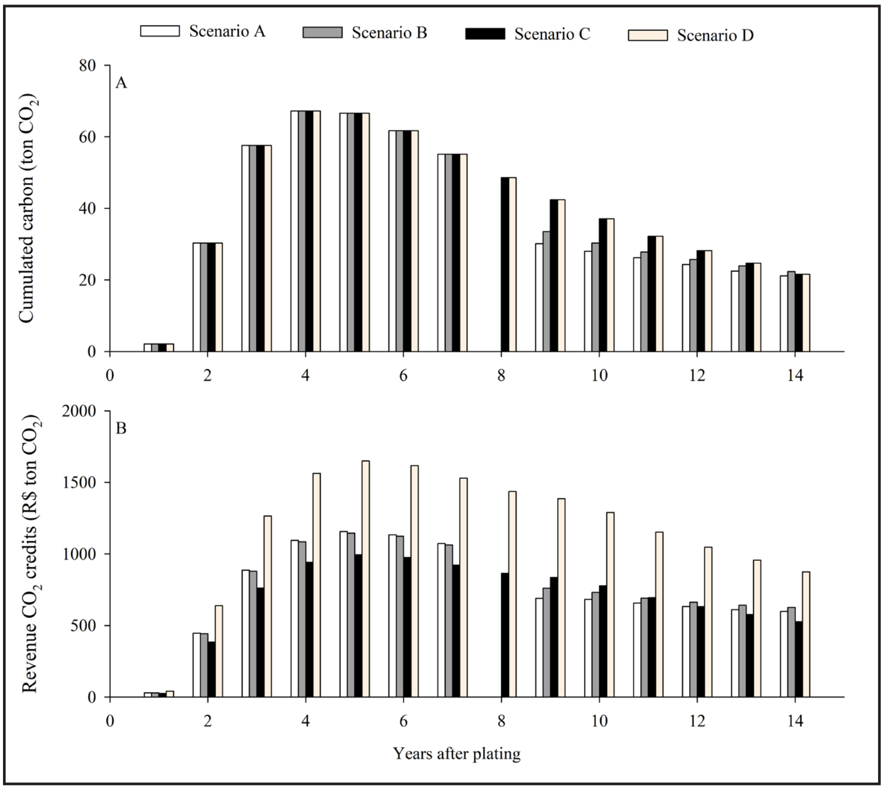
In where: A is a selective cut at year 7 and full cut at year 14; B is a systematic cut at year 7 and full cut at year 14; C is a full cut at year 14; Scenario (d) was not considered since no wood is cut or sold; NFV is the Net Present Value

In the last year, the NFV was R$ 6,286.56; 6,078.11; and 6,199.91 ha^{-1} $year^{-1}$ respectively in scenarios A, B, and C. The total profit future values were R$ 6,283.56 ha^{-1} $year^{-1}$ (Scenario A), R$ 6,078.11 ha^{-1} $year^{-1}$ (Scenario B), and R$ 6,199.91 ha^{-1} $year^{-1}$ (Scenario C) (Figures 4A, B, and C). In the last decades most (re)forestation projects have involved exotic species like eucalyptus, representing around 98% between 2003 and 2007 (THOMAS; JALONEN; LOO; BOSHIER; GALLO; CAVERS; BORDÁCS; SMITH; BOZZANO, 2014). The reason for this is mainly economic since exotic species are usually intended to feed industrial processes after forest cuts, generating higher revenue for the farmer (GONÇALVES; OLIVEIRA; CARVALHO; GOMIDE, 2017).

For the cumulated carbon, scenarios A, B, and C presented similar accumulation between 0 and 7 years with a total accumulated CO_2 of 55.1-ton CO_2 in the 7th year. In the last year, the total accumulated was 21.1; 22.3; 21.6; and 21.6-ton CO_2. These results were expected due to lower forest growth after 7 years of plant development (Figure 5A). Estimation models were developed and described in the literature (SCARFÓ; MERCURIO, 2009; SPECHT; WEST, 2003) provide the measurability of carbon sequestered by a tree, furthermore, in case the forest is harvested, the amount of carbon can be even measured by weighting the wood obtained after the forest is cut at the end of the cycle. All these methods are used for certification by companies active in this field.

During the forest growth, the revenue CO_2 credits were superior in Scenario D with the peak in the 7th year with a value of R$ 1,530.04-ton CO_2. The credit generated in the other scenarios was lower with a value of R$ 1,072.14-ton CO2; R$ 1,062.82-ton CO_2; and R$ 922.06-ton CO_2. In the last year, the Scenario D generated R$ 874.2806-ton CO_2 which was superior to Scenario A (R$ 598.45-ton CO_2), B (R$ 626.98-ton CO_2), and C (R$ 526.87-ton CO_2), Figure 5B. The available literature (BATISTA; NAKAJIMA; CHANG; HALISKI, 2011) analyzed the amount of revenue and profit given by forestry as traditionally intended by selling the wood, but it also focused on the fact that trees captured CO_2 as well and this can have a value in the market. The species of the trees played an important role in the forest, with a significant difference in the case of native or exotic monoculture since the amount of CO_2 sequestered depends on the tree species.

Figure 5 – Cumulated carbon (ton CO_2) and revenue CO_2 credits (R$ ton CO_2) in Scenario A, B, C, and D, in Sorriso, Mato Grosso, Brazil

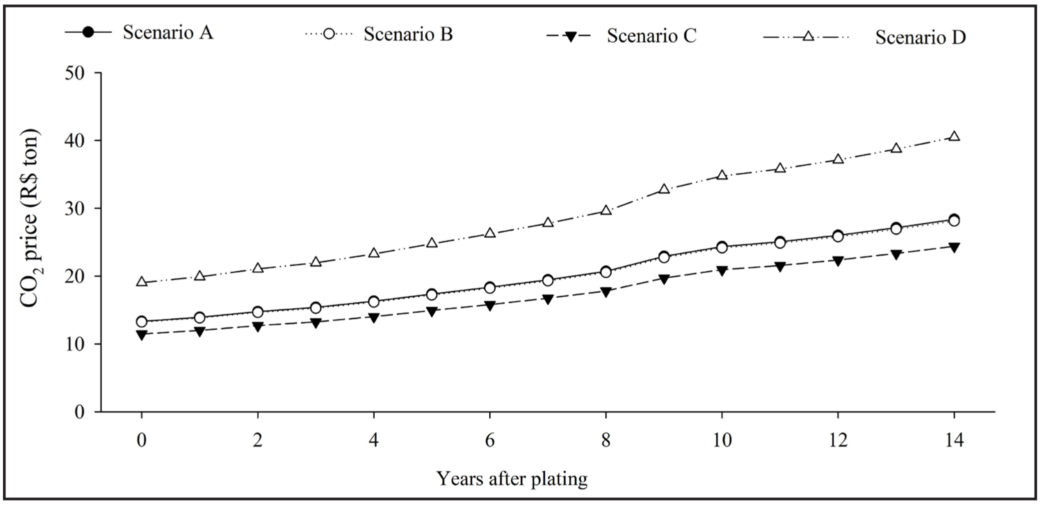


Source: Authors (2023)

In where: A is a selective cut at year 7 and full cut at year 14; B is a systematic cut at year 7 and full cut at year 14; C is a full cut at year 14; D is equivalent to the third one concerning the forest development, but no cut and therefore no income from the forest.

In scenarios, the CO_2 price was increased during the forest development with the highest price of R$ 40.47 ton-1 (scenario D), R$ 28.36 ton-1 (scenario A), R$ 28.11 ton-1 (scenario B), and R$ 24.39 ton-1 (scenario C), Figure 6. As a precondition to consider valuable carbon credits, principles of additivity, leakage, and permanence are satisfied: in fact, the farmer can choose the option not to use the land for the forest; once the forest is harvested the wood will be used for non-destructive industrial processes like furniture manufacturing, and the forest continues growing in the timeframe of cycles. Since 2021, the CME has launched a futures contract related to projects which fall under Agriculture, Forestry, or Other Land Use. The price of such a contract is quite volatile, spanning from 27 BRL at launch in August 2021 to 87 BRL in January 2022, stabilizing around 50 BRL since March 2022.

Figure 6 – Cumulated carbon (ton CO_2) and revenue CO_2 credits (R$ ton CO_2) in Scenarios A, B, C, and D, in Sorriso, Mato Grosso, Brazil



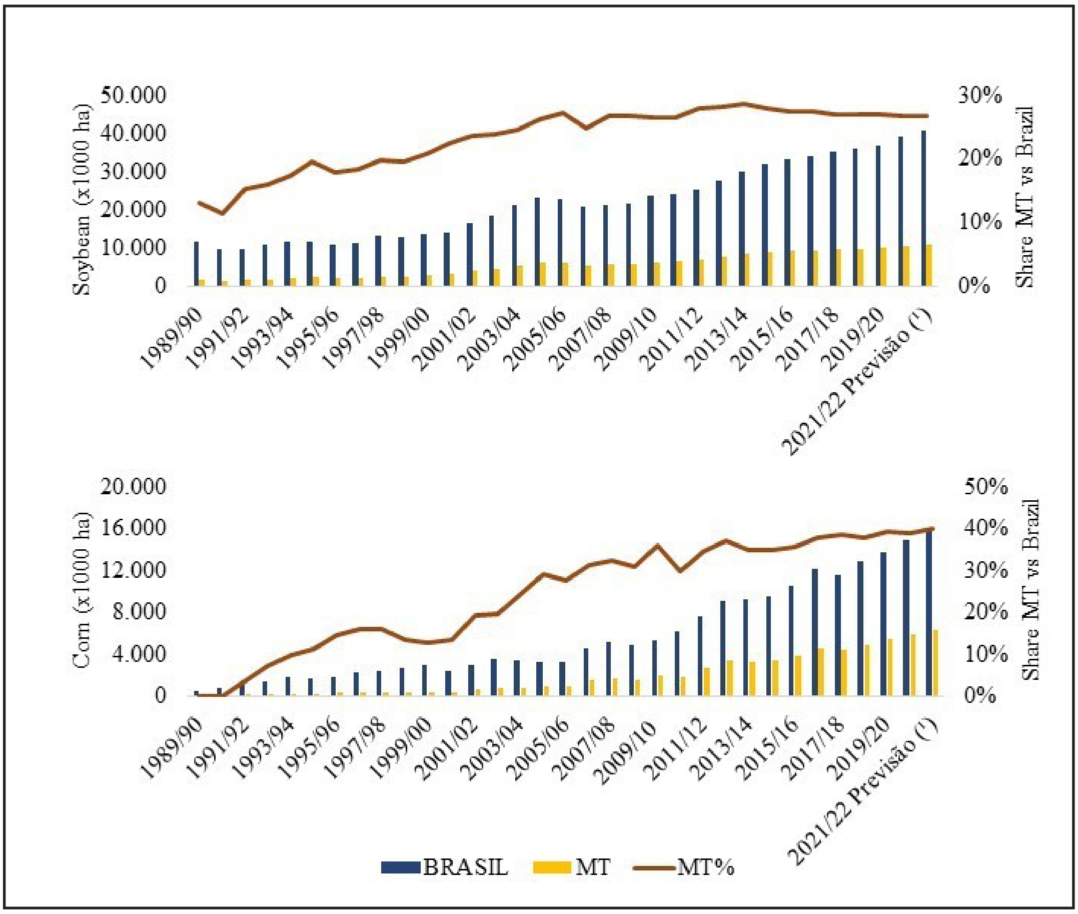
Source: Authors (2023)

In where: A is a selective cut at year 7 and full cut at year 14; B is a systematic cut at year 7 and full cut at year 14; C is a full cut at year 14; D is equivalent to the third one concerning the forest development, but no cut and therefore no income from the forest.

3.2 Grain production and profit

Corn and soybeans represent the most cultivated grain in Brazil, pushed by increasing market prices and profits for farmers (BARBOSA; PEREIRA; ARRUDA; BROD; ALMEIDA, 2018). The area cultivated with soybeans in MT – BR has an average representativeness of around 27% for the overall Brazilian cultivated area. Mato Grosso is the biggest soybeans producer in Brazil, its cultivated area has almost doubled since 2007, going from 5.675 thousand ha to 10.888 thousand ha in 2021 (Figure 7). In terms of productivity, Mato Grosso presented higher performances than average in Brazil. In the last two decades, it was between 3000 and 3500 kg/ha (FERRAZ-ALMEIDA; DA MOTA, 2021). As a consequence of the cultivated area increase and productivity improvement, the soybeans production in MT had grown 3,8 times in the last two decades, going from 9.641 in 2001 to 36.522 thousand tons in 2021 (Figure 7).

Figure 7 – Succession area of soybean and corn in Sorriso, Mato Grosso, Brazil, from 1989/90 to 2021/22



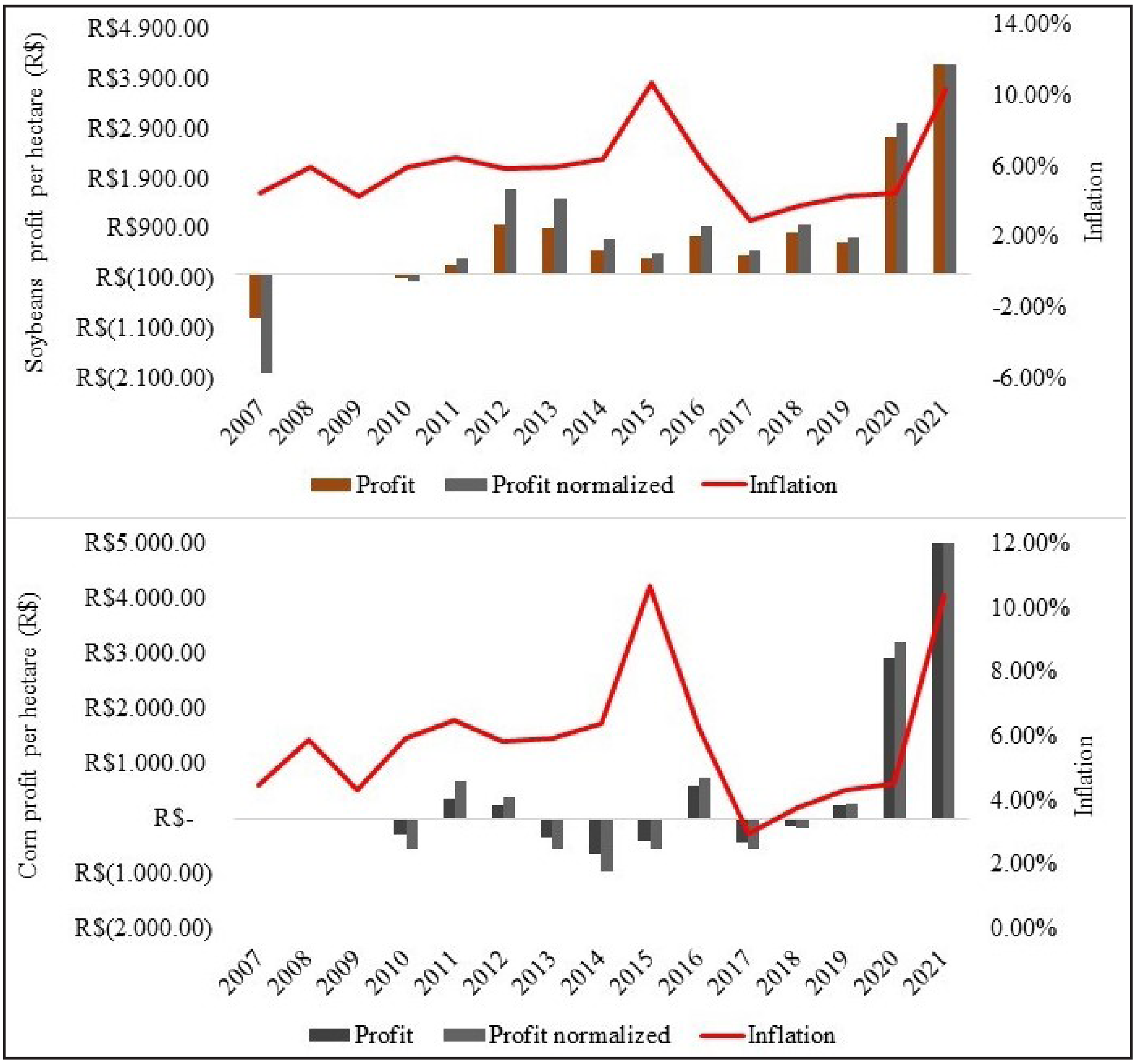
Source: Authors (2023)

The analysis considered that, in 2021, the area cultivated with corn represented around 60% of the area which was cultivated with soybeans for the 1st harvest. Technology applied to cultivation and seeds had consistently improved productivity over the years, this had more than doubled from 2.720 kg/ha in 2001 to 5.625 kg/ha in 2021 with some specific drops mainly related to climate conditions (lack of rain, etc..) (FARIA; VIEIRA; TENELLI; ALMEIDA; CAMPOS; COSTA; ZAVASCHI; ALMEIDA; CARNEIRO; OTTO, 2019; BACILIERI; OLIVEIRA; FERRAZ-ALMEIDA; MAGELA; LANA, 2023).

The productivity in MT registered better performances than average in Brazil. As a consequence of the cultivated area increase and productivity improvement, in the last two decades, the production in MT had exponentially grown from 953 thousand tons to 32.805 thousand tons (Figure 7).

In the timeframe 2007-2021, soybeans production was mainly characterized by positive profit, with the price increasing till 2012, then constant price till 2019 between 50 and 60 BRL per 60 kg, and finally a huge increase in 2020 and 2021 thanks to export demand and exchange rate BRL/USD (Figure 8).

Figure 8 – Soybeans and corn generated profit in the succession area of soybean and corn in Sorriso, Mato Grosso, Brazil, from 2007 to 2021



Source: Authors (2023)

Concerning corn, till 2019 the combination of productivity and price led to a revenue fluctuating between 1000 and 2000 BRL/ha, with the contribution of fluctuation of costs observed during such timeframe (Figure 8). The profit was consistently unstable between positive and negative as demonstrated well by the available studies (De Oliveira Neto, 2016), putting in doubt if it is worth it to cultivate corn for 2nd harvest instead of another culture more profitable despite the higher risk (e.g. cotton) ha (FERRAZ-ALMEIDA; DA MOTA, 2021). In 2020 and 2021 the situation has positively changed thanks to corn price increase in the international market and the raising exchange rate BRL/USD (Figure 8).

The combination of two crops in the same year using the same land generated double the income for the farmer ha (ALTARUGIO; SAVIETO; MACHADO; MIGLIAVACCA; ALMEIDA; ZAVASCHI; CARNEIRO; VITTI; OTTO, 2018). Normalized Added Value as of 2021 considering 14 years of land usage for soybeans planting was 12.812,09 BRL/ha. This is the number that represents the value generated by the farmer over that period. In the alternative, the number can be expressed as Net Present Value as in 2007, corresponding to 5.374,74 BRL/ha. Considering corn, the Normalized Added Value as of 2021 was 7.845,90 BRL/ha (3.284,09 BRL/ha if expressed as Net Present Value as in 2007) (Figure 8).

3.3 Crops and Forest Summarizing

Summing the combination of soybeans plus corn it obtained a Net Future Value in 2021 of R$ 20.657,99 per hectare, this is the number that needs to be equalized by forestry.

As expected, scenario c was the one that equals the business case with the minimum price of credit for tCO_2, being the scenario presenting the highest amount of CO_2 cumulated at the end of the cycle. With the forest characteristics set at the beginning of the case, the credit price between 11,47 (in 2007) and 24,39 BRL (in 2021) ensured equal profit per hectare as grain planting.

Interestingly was the result of case scenario D based on the hypothesis that the forest is not cut at all. Assuming no profit from forestry itself. Starting from scenario C, it simulated the price of tCO_2 equalizing R$ 20.657,99 considering just the revenue coming from trading of tCO_2 credits. Price around 40 BRL/tCO_2 in 2021 was able to ensure a successful business case, delivering a final value equivalent to grain production (Figure 10).

4 CONCLUSIONS

Summarizing the results according to the simulations performed with SISEucaliptus and prices premises set, one hectare of forest delivers a profit after 14 years of around 6.200 BRL/ha for the three scenarios, representing 32% of the profit that the same hectare would have delivered in case it was dedicated to grain production as in previous section. Such a result led us to consider that, at least in the timeframe 2007-2021 in the region considered, it was economically more beneficial to use the land for grain production, generating more than 14.000 BRL as the additional value per hectare.

Considering a eucalyptus commercial forest planted under the premises of the current study, results showed that a price of around 24 BRL per ton of CO_2 in 2021 is enough to turn it economically feasible. Business case had been estimated with and without profit coming from the commercial use of forest, and even assuming that no wood is cut and sold, the 2021 price of 40,48 BRL per ton of CO_2 can ensure more profit than grain production over 14 years timeframe, allowing the farmer to make money beyond the usual commercial use of a forest.

Forestry supported by CO_2 credits might be economically feasible and allows the farmer to generate the same amount of value as with benchmark cultures like soybeans and corn. The topic for future work can be the investigation of how the CO_2 voluntary market and related programs can be improved to increase their effectiveness.

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