JÚLIA GRAZIELA DA SILVEIRA

INTENSIFICATION OF AGRICULTURE AND LIVESTOCK BASED ON LOW CARBON TECHNOLOGIES IN THE AMAZON AND ATLANTIC FOREST

Thesis submitted to the Forest Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Sílvio Nolasco de Oliveira Neto

Co-adviser: Renato de Aragão R. Rodrigues

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Assent:

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Adviser

I dedicate this work to my family.

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“Ninguém é suficientemente perfeito, que não possa aprender com o outro e, ninguém é totalmente destituído de valores que não possa ensinar algo ao seu irmão”.

(São Francisco de Assis)

ABSTRACT

SILVEIRA, Júlia Graziela da, D.Sc., Universidade Federal de Viçosa, May, 2022. **Intensification of agriculture and livestock based on low carbon technologies in the Amazon and Atlantic Forest**. Adviser: Sílvio Nolasco de Oliveira Neto. Co-adviser: Renato de Aragão Ribeiro Rodrigues.

The Amazon and the Atlantic Forest are Brazilian biomes that have undergone intense land use and cover changes, marked by the loss of native forest and the expansion of agriculture and livestock. These are areas with potential use for intensification based on low-carbon technologies, but this change is still taking place slowly. Some factors need to be identified to guide promising solutions for this issue. Aiming at this, this study aimed to identify the land use and land cover in a historical series of 35 years in the Amazon and Atlantic Forest and describe the patterns of sustainable land use by producers who use this technique in the Amazon, identifying their characteristics and perceptions regarding the change developed in the farm. The statistics of the platform from the Annual Mapping Project for Land Use and Land Cover in Brazil (MapBiomas) were used in an annual historical series from 1985 to 2020. The analysis of land use and land cover changes indicates that the native forest of the Amazon was reduced by 44.53 million hectares (Mha), while pastures, agriculture and planted forest increased by 38.10, 6.06 and 0.26 Mha, respectively, over the 35 years. In the Atlantic Forest, for the same period, forest and pasture reduced by 0.99 and 11.53 Mha, respectively, while agriculture expanded by 8.06 Mha and planted forest by 2.99 Mha. Sustainable land use strategies, such as Integrated Crop-Livestock-Forest (ICLF) or Agroforestry Systems (AFS), can support increased agricultural production while recovering and preserving the environment. In view of this, we identified in the Amazon, the pattern of land use by farmers who adopt sustainable technologies, considering AFS and managed pasture monoculture (MP). The results were generated through interviews and analysis of qualitative and quantitative research that allowed the evaluation of producers in three states in the Amazon (Mato Grosso, Pará and Rondônia). In general, farmers in the Amazon are still risk averse and mainly implement MP. But when assessing the states in isolation, we realize that the producers in Pará and Rondônia are more approachable when it comes to moving to a diversified system. We did not find many differences in the profile of these producers, but we noticed that pasture adopters always have areas of larger properties and generally develop livestock as their main economic activity. On the other hand, AFS producers have smaller areas of property, conserve more forest and may have agriculture as the main activity of the property. Regional and local fitness, producer tradition and technology transfer can influence the decision of the adopted technology. There are great opportunities to improve agricultural and livestock practices with MP systems and AFS, demonstrated through improvements in farm income, productivity and environment. This evidence can be extrapolated to land use in the Atlantic Forest biome. However, we emphasize the need to consider regional characteristics, socioeconomic conditions and the perspectives of producers in the development of public policies and programs to encourage sustainable agriculture.

Keywords: Sustainable Development. Agroforestry System. Crop-Livestock-Forestry Integration. Rural Producer.

RESUMO

SILVEIRA, Júlia Graziela da, D.Sc., Universidade Federal de Viçosa, maio de 2022. **Intensificação da agricultura e pecuária baseada em tecnologias de baixa emissão de carbono na Amazônia e Mata Atlântica**. Orientador: Sílvio Nolasco de Oliveira Neto. Coorientador: Renato de Aragão Ribeiro Rodrigues.

A Amazônia e a Mata Atlântica são biomas brasileiros que sofreram intensas mudanças de uso e cobertura da terra, marcada pela perda de mata nativa e expansão da agricultura e pecuária. São áreas com potencial uso para intensificação baseada em tecnologias de baixa emissão de carbono, mas essa mudança ainda ocorre de forma lenta. Alguns fatores precisam ser identificados para que o caminho seja promissor. Visando isso, este estudo teve como objetivo identificar o uso e cobertura do solo em uma série histórica de 35 anos na Amazônia e Mata Atlântica e descrever os padrões de uso da terra sustentáveis por produtores que se utilizam dessa técnica na Amazônia, identificando as suas características e percepções quanto a mudança desenvolvida na propriedade. As estatísticas da plataforma do Projeto de Mapeamento Anual de Uso e Cobertura da Terra no Brasil (MapBiomas) foram utilizadas em uma série histórica anual de 1985 a 2020. A análise das mudanças de uso e cobertura da terra indica que a floresta nativa da Amazônia foi reduzida em 44,53 milhões de hectares (Mha), enquanto pastagens, agricultura e a floresta plantada aumentaram 38,10, 6,06 e 0,26 Mha, respectivamente, ao longo dos 35 anos. Na Mata Atlântica, para o mesmo período, a floresta e pastagem reduziram em 0,99 e 11,53 Mha, respectivamente, enquanto a agricultura expandiu 8,06 Mha e a floresta plantada em 2,99 Mha. Estratégias de uso sustentável da terra, como a Integração Lavoura-Pecuária-Floresta (ILPF) ou Sistemas Agroflorestais (SAFs), podem apoiar o aumento da produção agrícola ao mesmo tempo em que recuperam e preservam o meio ambiente. Visto isso, identificamos, na Amazônia, o padrão de uso do solo por produtores que adotam tecnologias sustentáveis, considerando o SAFs e o monocultivo de pastagem manejada (PM). Os resultados gerados por meio de entrevistas e análise de pesquisa qualitativa e quantitativa permitiu avaliar os produtores de três estados da Amazônia (Mato Grosso, Pará e Rondônia). De forma geral, os produtores da Amazônia ainda são avessos ao risco e implantam, principalmente, a PM. Mas, quando olhamos isoladamente para os estados, percebemos que os produtores do Pará e Rondônia são mais acessíveis quanto à mudança para um sistema diversificado. Não evidenciamos muitas diferenças no perfil desses produtores, mas percebemos que os adotantes de pastagem possuem sempre áreas de propriedades maiores e, geralmente, desenvolvem a pecuária como principal atividade econômica. Por outro lado, o produtor de SAF detêm menores áreas de propriedade, conserva mais a floresta e pode ter a agricultura como atividade principal da propriedade. A aptidão regional, tradição do produtor e transferência de tecnologia podem influenciar na decisão da tecnologia adotada. Existem grandes oportunidades para melhorar as práticas agrícolas e pecuárias com os sistemas de PM e os SAFs, demonstradas a partir de melhorias na renda, produtividade e ambiente de propriedades. Essas evidências poderão ser extrapoladas ao uso do solo no bioma Mata Atlântica. Entretanto, destacamos a necessidade de considerar características regionais, condições socioeconômicas e perspectivas dos produtores no desenvolvimento de políticas públicas e programas de incentivo a uma agricultura sustentável.

Palavras-chave: Desenvolvimento Sustentável. Sistema Agroflorestal. Integração Lavoura-Pecuária-Floresta. Produtor Rural.

SUMMARY

INTRODUCTION

The Amazon and Atlantic Forest are of great importance in terms of biodiversity [1–3] and have intense changes in landscape and land use [4,5], driven mainly by livestock and agricultural production [6–9], causing several environmental impacts due to deforestation to open new areas [10–12]. Controlling deforestation is essential to maintain the functional integrity of the forest [13], as this loss increases carbon emissions [14] and reduces its ability to provide ecosystem functions [15] which could have a negative impact on the productive sectors of agriculture.

In parallel, the world population continues to grow and it is expected that by 2050 the population will grow by 2 billion people, rising to 9.7 billion people [16]. However, changes caused by land use activities, lead to changes in climate and harmful effects on the performance of agricultural and livestock activities [17], which could affect food security and, more specifically, the availability at a reasonable price of food for a global population [18]. More pessimistic assessments state that the overall contribution of food production to global greenhouse gas (GHG) emissions which today represent 15%, could reach 30% [17].

Linked to this, there is a need to change land use activities, however, the challenges are significant, mainly related to agricultural and animal production [17]. The challenge of increasing production and raw materials by the agricultural sector will require ecologically, economically, socially and efficient strategies to reduce the production gap (the difference between actual and potential yields) in order to encompass environmental benefits, but also achieve better access to relevant technologies at different sizes and ownership levels [19,20].

To address these challenges, there is a need to identify and implement agricultural practices that can provide greater environmental benefits, while maintaining or improving food production and rural incomes in the face of resource constraints [21]. For this, it is necessary to make food production more effective, based on zero illegal deforestation, using already open land, with pasture areas [22,23]. Of the 162.9 million hectares (Mha) of pastures in Brazil, 89 Mha have some degree of degradation and the Amazon and Atlantic Forest appear in second and third place, respectively, in the ranking of areas with pastures [24] enabling the implementation of sustainable practices for recovering of those pastures.

Rural producers can, at the same time, contribute to food security and also to the mitigation of climate change, by carrying out forest restoration and adopting low-carbon technologies with the sustainable intensification of their production [19,25]. In order for the adoption of more complex technologies and the environmental, social and economic benefits to be spread correctly, it is necessary to focus on adequate technical assistance and financial incentives, especially among small and medium-sized producers [26,27]. This assistance can come from decision makers through public policies, research and rural extension and local projects, which will directly lead to the provision of various ecosystem services [28,29].

Although there are studies on the economic and environmental benefits of low-carbon technologies [19,25,30–32], there are few that try to understand the characteristics of producers who implement these technologies, as well as their perception of these practices. The absence of local perspectives is worrying, since the producers are the central point of that theme, as they are the people who make the decision to adopt a certain practice, influenced by extension agents [33].

Information on agronomic and economic improvement of systems is unlikely to result in favorable changes in the adoption of sustainable agriculture if structural barriers (e.g. technical assistance, rural extension, technology transfer and rural credit) are not overcome and if farmers are not convinced [21]. They will also have no effect if the projects do not consider the local reality and conditions of the producer. It is essential that research and development efforts have approaches that also integrate the characteristics of the population that adopts this technology for dissemination to other groups.

In this way, this study seeks to overcome the knowledge gap on current land use and sustainable alternative uses, so that it can collaborate with public policies in the transition to sustainable agriculture. For this, it aimed to identify land use and land cover in a 35-year historical series in the Amazon and Atlantic Forest, describe sustainable land use patterns and characterize the rural producers who are dedicated to this use in the Amazon.

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Chapter 1 - Land Use, Land Cover Change and Sustainable Intensification of Agriculture and Livestock in the Amazon and the Atlantic Forest in Brazil [1]

1. Introduction

Approximately 70% of the earth's surface has already undergone some type of anthropogenic alteration, converting native forests for agricultural production, infrastructure, and urban use [1]. These changes reduce the performance of agricultural and livestock activities [2], which can affect food availability [3] for a growing global population [4].

Land use time series show that Brazil lost 71 Mha of native forest over 34 years, due to the expansion of pasture areas (by 46%) and agricultural areas (by 172%) [5]. In this setting, we highlight the Amazon and Atlantic Forest biomes as they host intense activities in these sectors, representing 81% of agricultural production [6] and 57% of the pasture herd of Brazil [7].

These biomes have rich and diverse species, including endemic ones [8–11]. The Amazon has the most extensive remaining tropical forests in the world (approximately 60%), making it a biodiversity hotspot [12], and essential in the mitigation of climate change [13]. However, the expansion of livestock and agriculture, mainly in the southern and eastern regions [14] has accelerated the loss of native forest [15].

The Atlantic Forest is represented by landscapes of small forest fragments marked by deforestation [16], where only 12% of native forest cover remains [17]. Approximately 70% of the Brazilian population lives in this biome [18], which has driven massive industrialization and agricultural expansion, replacing forest areas [19]. This biome is considered one of the three hotspots most vulnerable to global warming [20].

The Amazon is at serious risk due to the proportion of native forest, creating direct and indirect incentives for landowners and land grabbers to advance illegal deforestation [21], driven mainly by the expansion of agricultural and pasture areas [22]. Meanwhile, with small, isolated forest patches [23,24], the Atlantic Forest is on the verge of ecosystem collapse and catastrophic loss of biodiversity due to the magnitude and extent of deforestation [25].

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[1] Silveira, J.G.d.; Oliveira Neto, S.N.d.; Canto, A.C.B.d.; Leite, F.F.G.D.; Cordeiro, F.R.; Assad, L.T.; Silva, G.C.C.; Marques, R.d.O.; Dalarme, M.S.L.; Ferreira, I.G.M.; et al. **Published in:** *Sustainability* 2022, Volume 14, Issue 5, 2563. https://doi.org/10.3390/su14052563

This critical setting of intense changes in land use and land cover is still poorly investigated at present, especially in the Atlantic Forest [26]. Understanding how land use changes over time and space and how this affects landscape structure are essential factors in managing ecosystem services and species conservation, neutralizing threats to biodiversity [27–30]. Then, we should prevent and minimize undesirable impacts, such as reducing agricultural productivity [31]. Exploring this landscape change through a land-use historical series can provide decision-making and support land-use planning to strengthen social, economic, and environmental development [5].

A set of strategies is necessary to reconcile the need to provide livelihoods for the residents of the regions, food for the population and conservation of the native forests that still remain [27]. New land use practices, agricultural and livestock strategies and technologies that support sustainable intensification can foster environmental conservation without compromising food production [32–34]. In this context, understanding the temporal dynamics of land use and land cover changes and current land use becomes an essential factor in overcoming sustainability challenges in the Amazon and Atlantic Forest.

Thus, this study aims to present an analysis of land use and land cover in the Amazon and Atlantic Forest, in a historical series from 1985 to 2020 through available data from MapBiomas, and with that to identify the main changes that occurred in these 35 years. Subsequently, we identified the main drivers of these changes through the literature and proposed a sustainable strategy, analyzing the main barriers to its adoption.

2. Materials and Methods

2.1. Study Area

The selected study areas were the Brazilian Amazon and Atlantic Forest biomes (Figure 1). The Amazon extends to the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, Mato Grosso and Maranhão, comprising 558 municipalities and occupying an area of 5 million square kilometers. The Atlantic Forest extends from Rio Grande do Norte to Rio Grande do Sul, comprising 3082 municipalities and an area greater than 1.1 million square kilometers [35].

Figure 1. Map of Brazil, with the Amazon biome colored in dark green and the Atlantic Forest in light green. Country and biome boundary data from IBGE [36].

2.2. Spatial and Temporal Trends in Land Use and Land Cover

We used data from the sixth collection of the MapBiomas platform, in an annual historical series from 1985 to 2020 [37]. The data are generated from the automated processing of Landsat 5 Thematic Mapper™, Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 sensors e Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS). The Landsat imagery collections with 30 m pixel resolution were accessible via Google Earth Engine and produced by NASA and USGS [37]. The general accuracy for the Amazon biome was 96.6%, with 2.4% allocation disagreement and 1.0% area disagreement [38]. In the Atlantic Forest biome 85.5% of general accuracy, 8.3% of allocation disagreement and 6.2% of area disagreement [38].

The land cover and land use classification scheme by MapBiomas is a hierarchical system compatible with the classification systems of the Food and Agriculture

Organization (FAO) [39] and Brazilian Institute of Geography and Statistics (IBGE) [40], which have different levels and classes. We considered six land use and land cover classes, according to level 2 of the land cover and use classification system for MapBiomas in Brazil [41], as follows: (1) Native forest (includes forest formation, savanna formation, mangrove and wooded restinga); (2) pasture; (3) agriculture (includes temporary crop and perennial crop); (4) forest plantation; (5) mosaic of agriculture and pasture and; (6) other land uses (includes non-forest natural formation, non-vegetated area, water and non-observed).

Below is a brief description of each land use and land cover classes, according to MapBiomas [41] and Souza et al. [5].

1. Native forest: land cover with predominance of tree species with continuous high-density canopy; and/or with a tree layer varying in density, distributed over a continuous shrub-herb layer; and/or dense and always green, often flooded by the tide;

2. Pasture: referring to pasture areas, natural or planted, linked to livestock activity;

3. Agriculture: agricultural cultivation areas, occupied with temporary crops (soybean, sugarcane, rice, and other temporary crops) and perennial crops (coffee, citrus, other perennial crops);

4. Planted forest: area with tree species cultivated for commercial purposes;

5. Mosaic of agriculture and pasture: areas of agricultural use where we could distinguish between pasture and agriculture, found only in the Atlantic Forest;

6. Other land use: several uses outside the interest of this research were grouped. This use was used only to identify the territorial proportion for the years 1985 to 2020 and in the constructed map. It was not considered in the annual historical series.

According to Martinez et al. [42], land use is related to the human interactions with the land surface, while land cover is related to the natural earth's surface characteristics. The description of each class can be checked in detail in MapBiomas General "Handbook" [41].

The land use and land use and cover change during the years 1985 and 2020 were performed obtaining:

- Quantification of the area in Mha of each land use and land cover classes for 1985 and 2020. These values were obtained from MapBiomas database.

- Percentage of territorial occupation (%) of each land use and land cover classes for 1985 and 2020 (Equation (1)):

$$Territorial\ occupation\ (\%) = \left(\frac{area\ of\ the\ verified\ class}{total\ area\ of\ the\ biome}\right) 100 \quad (1)$$

- Difference class area (hectares) between the years (1985 and 2020) to verify the increase or decrease in a specific class in territorial occupation through Equation (2) [43]:

$$Land\ use\ and\ land\ cover\ change\ (Mha) = final\ year\ area - initial\ year\ area \quad (2)$$

We also analyzed land use and the rate of land use change annually, from 1985 to 2020, through:

- Quantification of the area (Mha) of each land use and land cover classes (except “other uses”) for all selected years (1985 to 2020). These values were obtained from MapBiomas database.
- Annual land use and land cover change rate (%) for all selected years (1985 to 2020) in each land use and cover classes (except “other uses”), through Equation (3) [43]:

$$Annual\ land\ use\ and\ land\ cover\ change\ rate\ (\%) = \left(\frac{(Area\ of\ current\ year\ -\ Area\ of\ previous\ year)}{Area\ of\ previous\ year}\right) 100 \quad (3)$$

When the results were negative, it meant a decrease in the area and the territory percentage. The results were positive when there was no negative sign, and there was an increase in the land use class.

A simple linear model (Equation (4)) was fitted for each land use and land cover class, with the relation of the area as a function of time. These adjustments were analyzed through the significance of the $\beta1$ parameter ($\alpha = 0.05$) to verify the trend of each land use and land cover over the observed interval (1985 to 2020) [44–47]:

$$y = \beta0 + \beta1x + \varepsilon \quad (4)$$

where: y = area (Mha); $\beta0$ and $\beta1$ = regression parameters; x = year; ε = random error.

The discussion and the comprehension of land use and land cover changes over the analyzed period were based on the literature, and historical social and political events that triggered the land use and land cover change.

To help with the discussion, we created a map representing the land use and land cover changes in the study areas in 1985 and 2020, presented as a result. Thus, an analysis was performed using ArcGIS software tools, combining the layers of information over the different years.

This paper also explored possible actions for the future in biomes through a literature-based discussion, which allows better identification of necessary tools for land use aiming for sustainable development in the Amazon and Atlantic Forest biomes

2.3. Animal Stocking Rate Over 35-Year Period

Data from the livestock herd time series were employed through the Municipal Livestock Survey (PPM), obtained by the Brazilian Institute of Geography and Statistics (IBGE) from 1985 to 2018, for all municipalities belonging to the Atlantic Forest and the Amazon [7]. These data provide the basis for analyzing the livestock head number and animal stocking rate. For this analysis, all animals managed in pastures were selected: cattle, horses, buffaloes, goats, and sheep. The information was extracted at the municipality level and grouped at the biome level annually. The PPM data were obtained through consultations with qualified informants in the production chain, governments, and other market agents, which resulted in estimates based on technical knowledge and administrative records. Concerning cattle information, IBGE also considers the vaccination campaign against Foot-and-Mouth Disease in the municipality. The livestock herd is counted regardless of type, sex, age, breed, or purpose [48].

The temporal analysis of the livestock herd was based on the total head in millions (M heads) obtained from PPM. The stocking rate (head ha^{-1}) was calculated annually (1985 to 2020), based on Equation (5):

$$Animal\ stocking\ rate\ (head\ ha^{-1})\ = \left(\frac{Total\ animal\ head}{total\ pasture\ area}\right) \tag{5}$$

3. Results

3.1. Spatial and Temporal Trends in Land Use and Land Cover

3.1.1. Amazon Biome

The Brazilian Amazon was represented originally by an area of 420.77 Mha. Of this total, in 1985, native forest represented the primary land use, covering 89.02%, with 374.57 Mha. The class “other land use”, including non-forest natural formation, non-vegetated area, water, and those not observed, covered 6.55% (27.58 Mha) of the biome. Pasture reached about 4% of the territory in that same year, occupying 18.54 Mha. The minority classes of land use in terms of extension were agriculture (0.08 Mha), followed by planted forest (0.003 Mha), which together represented 0.02% of the territory (Table 1).

Table 1. Total area (Mha) and territorial proportion (%) of different land use and land cover classes for the years 1985 and 2020. The land use and land cover changes (Mha) consider the period of 35 years (between 1985 and 2020) for each land use and cover in the Amazon biome.

Land Use and Land Cover	**1985**		**2020**		**Land Use Change (Mha)**
	Area (Mha)	**Territorial Proportion (%)**	**Area (Mha)**	**Territorial Proportion (%)**	
1. Native forest	374.57	89.02%	330.03	78.44%	−44.53
2. Pasture	18.54	4.41%	56.65	13.46%	38.10
3. Agriculture	0.08	0.02%	6.13	1.46%	6.06
4. Forest plantation	0.003	0.001%	0.27	0.063%	0.26
6. Other land use	27.58	6.55%	27.69	6.58%	0.11
Total	420.77	100.00%	420.77	100.00%	

A total of 44.53 Mha of native forest were converted into 38.10 Mha of pasture. The other 6.43 Mha of forest lost were converted into agriculture (6.06 Mha) and planted forest (0.26 Mha) areas. Thus, in 2020, the native forest represented 78.44% (330.03 Mha) of the territory, while the pasture covered 13.46% (56.65 Mha) of the total area, the second-largest land use in the Amazon. In 1985, agriculture represented only 0.02% of the territory, and 1.46% (6.13 Mha) of the territory in 2020. The planted forest covered 0.06% (0.27 Mha) of the territory in 2020, while “other land use” represented 6.58% (27.69 Mha), and was the class that achieved the lowest gains in the period (Table 1).

Observing the annual historical series from 1985 to 2020 (Figure 2A), all land uses evidence the significance of the parameter β1 ($\alpha < 0.05$), which shows a declining trend (dashed line in Figure 2A) of the native forest over these years, while the other uses (pasture, agriculture, planted forest) increased.

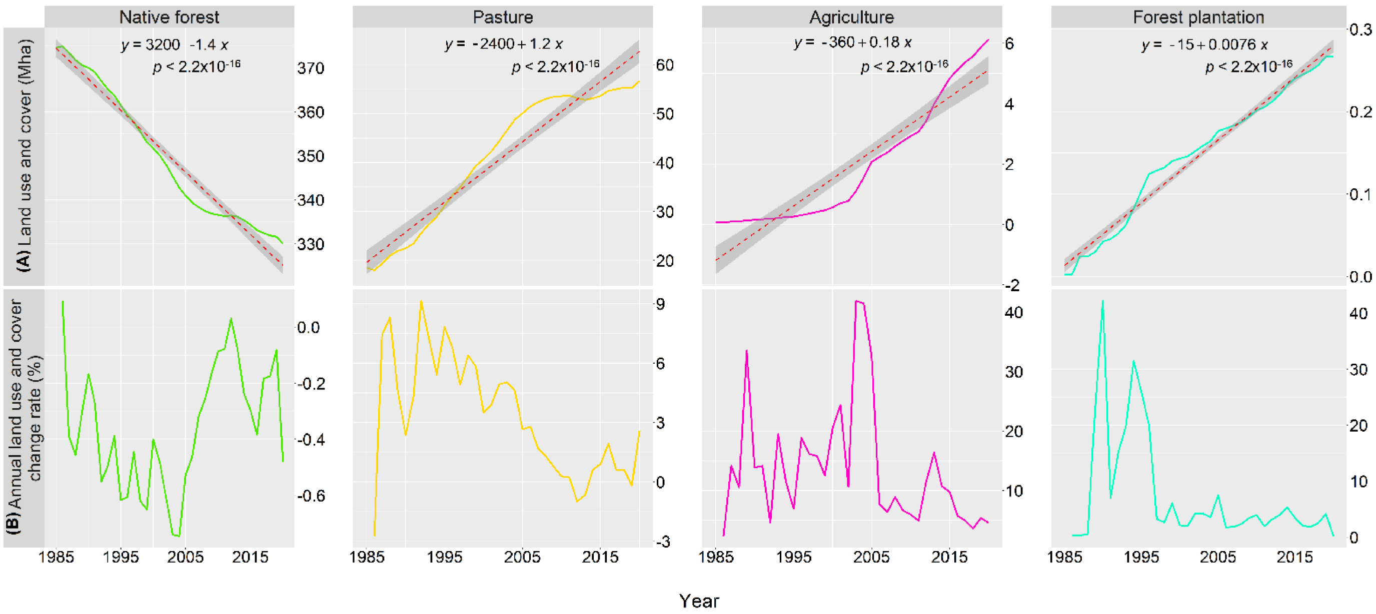

Figure 2. Land use and land cover (**A**) for the primary classes for Amazon, where the dashed line refers to the simple linear regression. Annual land use and land cover change rate (**B**), where the values above zero represent an area increase, and values below zero represent loss of area when compared to the previous year. Land use and land cover data refer to MapBiomas [37].

The annual losses of native forest ranged from −0.08% to −0.75%. The conversion occurred mainly between 1991 and 2005, with mean annual losses of −0.56% (−2.00 Mha per year), equivalent to a total reduction of −28.02 Mha of land (Figure 2A). In this same period of significant loss of native forests, pasture increased by 26.62 Mha, with mean annual gains of 5.58% (Figure 2A,B).

After this period, the rate of loss of native forest area decreased between 2005 and 2011, with a mean of −0.23% per year, until reaching the lowest rate recorded in 2012. However, the levels of forest loss returned to increase and surpassed −1.60 Mha in the 2019–2020 period (−0.48% of the territory with native forest) (Figure 2A,B). The loss of native forest was mainly for pasture, which increased by 1.43 Mha in that period (Figure 2A).

Overall, the land use class pasture's area increase ranged from 0.22% to 9.14%. This class had few territorial losses over the 35 years, but it decreased (−2.73%, −0.51 Mha) in the 1985–1986 period, when mainly replaced by agriculture. The increases were mainly recorded from 1991 to 1999 (mean annual of 6.69% per year) (Figure 2B). In that same period, the average area gain was 1.98 Mha per year.

Agriculture showed an increase in area over the 35 years (Figure 2A,B). The period 2002 to 2005 represented the biggest increase, with an average gain of 38.59%

per year (total increase of 1.29 Mha). The sum of area gained in these periods represented 22% of the entire increase. The slowest pace of agriculture area gain was observed between 2005 and 2011, and 2015 and 2020, with an annual average of 5.88% (Figure 2B).

The same pattern of the land use class of agriculture was observed in the planted forest, with an increase throughout 1985 to 2020 (Figure 2A,B). However, in terms of extension, as shown in Table 1, the planted forest area is still a minority. During the period of 1989–1990 that land use had the highest rate of increase, with 42.18% (Figure 2B), representing an increase of 0.01 Mha (Figure 2A). From 1993 to 1995, the territorial increase was an average of 28.75% per year (total increase of 0.04 Mha). Overall, after 1996, the annual rate of increase was lower (average of 3.24% per year) compared to previous years. In the period of 2019–2020 it was observed to have the lowest annual increase rate (0.21%).

In the last evaluated period (2019–2020), native forest had a total area loss of −0.84%, while pasture, agriculture and planted forest grew together by 7.35%, representing an increase of 1.70 Mha converted from the other uses.

3.1.2. Atlantic Forest

The Brazilian Atlantic Forest is represented by a total area of 110.66 Mha. In 1985, this territory was covered mainly by pasture areas, which constituted 36.14% (39.99 Mha) of the area, followed by native forest, which occupied 29.74% (32.91 Mha). The agriculture and pasture mosaic is the third largest land use class, representing 17.40% (19.26 Mha), followed by agriculture (9.68%, 10.71 Mha) and “other land uses” (6.28%, 6.95 Mha). The minority class of land use regarding extension was planted forest, which represented only 0.77% (0.85 Mha) of the territory in that same year (Table 2).

Table 2. Total area (Mha) and territorial proportion (%) of different land use and land cover classes for the years 1985 and 2020. The land use and land cover change (Mha) consider the period of 35 years (between 1985 and 2020) for each land use and cover in the Atlantic Forest biome.

Land Use and Land Cover	1985		2020		Land Use Change (Mha)
	Area (Mha)	**Territorial Proportion (%)**	**Area (Mha)**	**Territorial Proportion (%)**	
1. Native forest	32.91	29.74%	31.92	28.84%	−0.99
2. Pasture	39.99	36.14%	28.46	25.72%	−11.53
3. Agriculture	10.71	9.68%	18.78	16.97%	8.06
4. Forest plantation	0.85	0.77%	3.84	3.47%	2.99
5. Mosaic of Agriculture and Pasture	19.26	17.40%	20.14	18.20%	0.89
6. Other land uses	6.95	6.28%	7.53	6.80%	0.58
Total	110.66	100.00%	110.66	100.00%	

The land use and land cover changes were mainly driven by a loss of pasture and native forest area and a gain of area in agriculture and planted forest area (Figure 3A) over the 35 years, resulting in a reduction of −11.53 Mha of pasture and −0.99 Mha of native forest, which were converted into 8.06 Mha of agriculture, 2.99 Mha of planted forest, and 1.47 Mha from the sum of agriculture, pasture, and other land uses (Table 2).

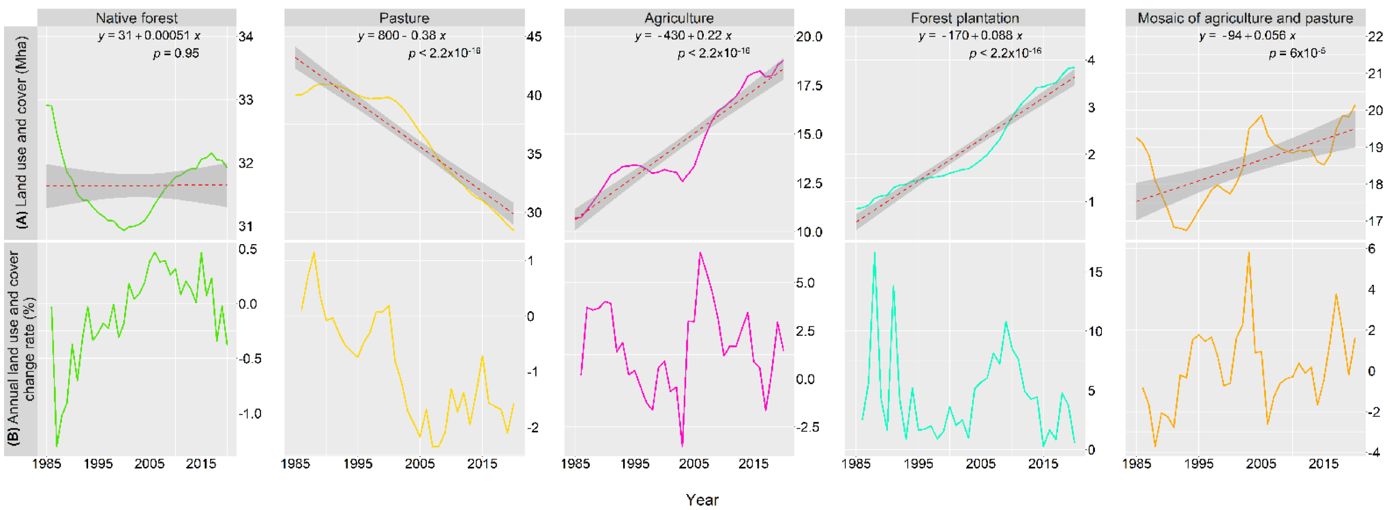

Figure 3. Land use and land cover (**A**) for the primary classes for Atlantic Forest, where the dashed line refers to the simple linear regression. Annual land use and land cover change rate (**B**), where the values above zero represent an area increase, and values below zero represent a loss of area when compared to the previous year. Land use and land cover data refer to MapBiomas [37].

In 2020, the native forest still represented the primary land use in this biome (28.84%, 31.92 Mha), followed by pasture (25.72%, 28.46 Mha), agriculture and pasture mosaic (18.20%, 20.14 Mha), agriculture (16.97%, 18.78 Mha), other land uses (6.80%, 7.53 Mha) and planted forest (3.47%, 3.84 Mha). Even though the native forest represents the primary land use, it is essential to highlight that there were losses, but in a smaller proportion than the pasture and therefore it became the most representative class (Table 2).

Observing the annual historical series from 1985 to 2020 (Figure 3A), except for native forest, all classes show the significance of the β 1 parameter ($\alpha < 0.05$), which indicates that the native forest area fluctuated over the 35 years, with mean values of 31 Mha. The pasture showed a trend (dashed line in Figure 3A) of territorial loss, meanwhile agriculture, planted forest and agriculture and pasture mosaic showed a gain trend.

In the analyzed time interval, the native forest class was converted mainly from 1986 to 1991, with total area losses of −4.39%. During that period, 1.39 Mha were converted mainly into agriculture, planted forest, and other land uses. On the other hand, from 2000 to 2017, the native forest had a mean annual area growth of 0.23% (1.23 Mha total). However, native forest areas were again converted into other uses from 2017 to 2020, with accumulated losses of −0.74% (Figure 3A,B).

In the pasture class, there were few signs of annual expansion of the area. This increase was observed only from 1985 to 1989, with a total gain of 2.32% (0.93 Mha), and from 1997 to 2000, with an increase of 0.35% (0.93 Mha). In these periods, the pasture occupied mainly areas of native forest and agriculture and pasture mosaic (Figure 3A,B).

From 2000 onwards, pasture areas shrunk on average −1.66% per year and resulted in the conversion of −11.36 Mha (Figure 3A,B). Overall, from 2000 to 2003, pasture was mostly converted to planted forest and agriculture and pasture mosaic. From 2000 to 2003, pasture was mainly converted into planted forest and agriculture and pasture mosaic. From 2003 to 2015, pasture areas were mainly replaced by agriculture and planted forest, and, later, the mosaic of agriculture and pasture also increased.

The agriculture class recorded loss periods, which resulted in −9.55% of lost area (−1.34 Mha in total), mainly identified in 2002–2003 (−3.51%). The lost areas were mainly converted into agriculture and pasture mosaic and planted forests. These periods were offset by the territorial gain from agriculture, which occurred in most of the years analyzed and totaled 9.40 Mha (mean annual of 2.39%).

Area gains from agriculture were more intense from 1986 to 1991 (average of 3.77% per year) and from 2005 to 2009 (average of 4.95% per year). The gains in these periods resulted in a total increase of 5.04 Mha, relative to 62% of the total area gain in the 35-year interval (Figure 3A,B).

Although the territorial representation of forest plantations is the lowest among the land uses, this was the only class with recurrent increases throughout the entire evaluated period. The 1987–1988 and 1990–1991 periods were the primary peaks of planted forest area increase, with 16.64% and 13.83%, respectively (Figure 3B). This increase resulted in 0.31 Mha of new planting areas. The 2006–2011 period recorded a mean annual increase of 8.46% (mean annual of 0.20 Mha). The lowest rate of planted forest increase was recorded in the 2014–2015 period, with 0.28% (Figure 3A,B).

The mosaic class of agriculture and pasture area decreased, on average, −1.20% per year, identified mainly from 1987 to 1991 (mean annual of −2.69%). The area increase ranged from 5.81% (2002–2003) to 0.17% (2012–2013) (Figure 3B).

In the 2019–2020 period, native forest and pasture had total area losses of −2.42% (−0.61 Mha), while agriculture, planted forest, and agriculture and pasture mosaic grew together (3.62%) (Figure 3A,B).

3.1.3. Land Use and Land Cover Overview

When considering the spatial distribution of classes in 1985 and 2020, we can see the main expansion regions for each use, as shown in Figure 4 (1985 and 2020). In the Amazon, the most evident changes at this map scale are the expansion of pastures covering formerly native forest areas (Figure 4). We noticed that pasture expanded throughout the entire biome, even with the highest concentrations to the east and southwest. In contrast, agriculture areas were concentrated in the southern region of the Amazon bordering with the Cerrado biome.

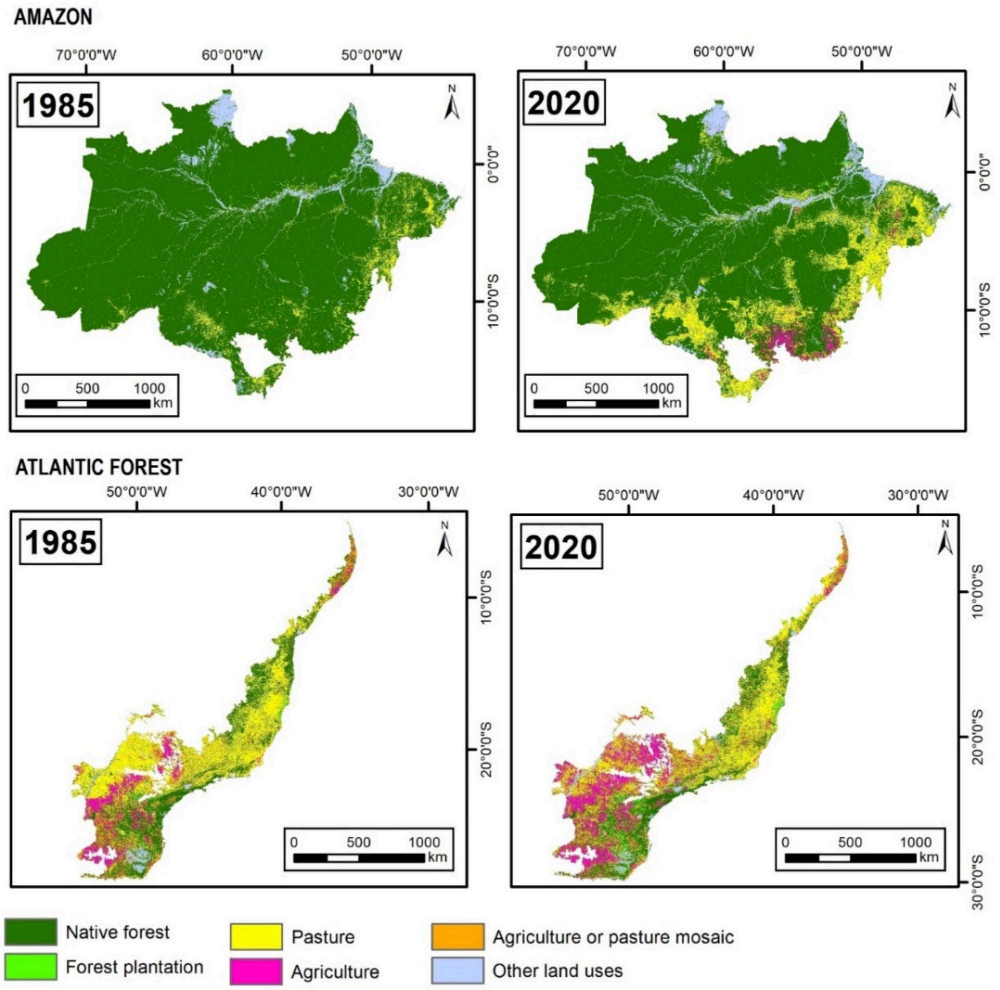

Figure 4. Land use and land cover observed in 1985 and 2020 in the Amazon and Atlantic Forest biomes. Land use and land cover are provided from MapBiomas [37], country and biome boundary data from IBGE [36].

The Atlantic Forest has an older occupation history. In 1985, we already observed the territorial extension of pastures, which were gradually replaced by agricultural areas (2020), mainly in the southwest region of the biome (Figure 4).

3.2. Animal Stocking Rate Over 35 Years

The increase in the number of livestock in million (M) heads in 35 years (1985–2020) outpaced the growth of the pasture area, both in the Amazon and the Atlantic Forest (Figure 5).

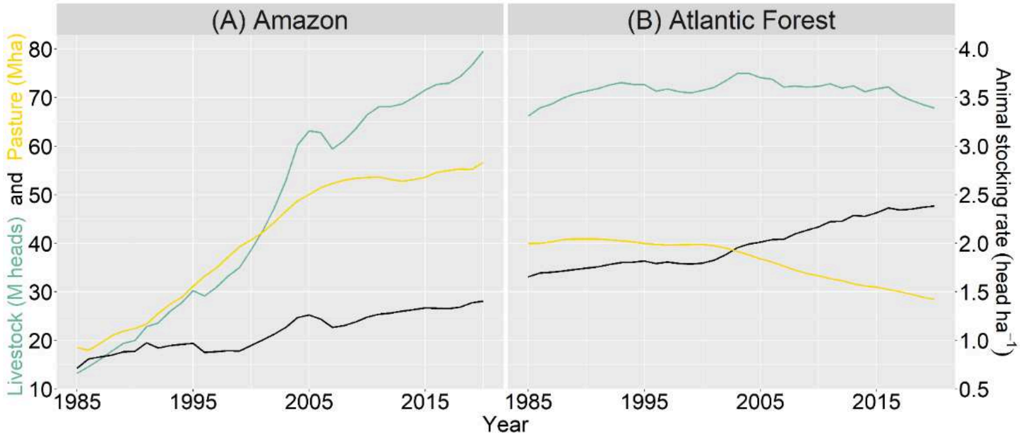

Figure 5. Livestock herd, pasture area and animal stocking rate (relation between the livestock herd and pasture area) for the Amazon (**A**) and Atlantic Forest (**B**) biomes.

In the Amazon biome, the livestock went from 13.25 M heads (1985) to 79.57 M heads (2020), a six-fold increase, while the pasture area increased three-fold in the same period. Thus, in the last 35 years, the Brazilian Amazon has increased the stocking rate of its pastures, from 0.71 head ha^{-1} (1985) to 1.40 head ha^{-1} (2020), contributing to the increase in this parameter by 97% (Figure 5A).

In the Atlantic Forest, while the pasture area shrunk (−29% of area), the livestock increased, from 66.22 M heads (1985) to 67.88 M heads (2020), with an increase of 1.66 M heads in the pasture areas. As a result, the mean stocking rate hiked from 1.66 to 2.39 M heads per hectare of pasture (Figure 5B).

4. Discussion

4.1. Land Use and Land Cover

4.1.1. Amazon Biome

The 1991 to 2005 period recorded the highest native forest loss rates, caused mainly by country's economy transitions, with constant incentives for the migratory flow, tax incentives, expropriation of vacant land for agricultural projects, rural credit, tax exemptions and land concessions for investments in the region, highest rates of loss of native forest, caused mainly by transitions in the country's economy with constant incentive for the migratory flow, tax incentives, expropriation of vacant land for agricultural projects, rural credit, tax exemptions and land concessions for investments in the region [11,49,50]. An increase in the agriculture and livestock area was recorded in the same period and was driven by direct government incentives to meet the growing international demands for soy and beef [51].

After a period of high loss of native forest areas in the Amazon, we observed a slowdown in the deforestation pace from 2005 to 2014, with several actions explaining this event, which include the command-and-control inspection actions by state and federal agencies [52–55], the creation of plans such as the “Action Plan for the Prevention and Control of Deforestation in the Legal Amazon” (PPCDAm) [56] and restrictions on credit available to illegal deforesters [57–59], the creation of public lists of properties and municipalities with illegal deforestation [60], the establishment of new protected areas [61] and the moratoriums to eliminate illegal deforestation from production chains for soybeans (e.g., Soybeans Moratorium) and beef (e.g., Meat Conduct Adjustment Agreement) [62–64].

Recently, the deforestation pace has picked up again, particularly in 2019–2020, to convert native forests into agriculture and pasture areas. As predicted by Rodrigues et al. 2019, the reason for this may be directly associated with the exhaustion of some environmental policies [62,65]. For example, the anti-environmental discourse of the current Brazilian government [66], which focuses on dismantling environmental structures and legislation [67]. Among several negative actions, the government took an adverse approach to the Amazon Fund, resulting in a loss of US$1 billion in funds to preserve the Amazon [68,69], besides inciting illegal activities, such as land grabbing, mining, and logging [70].

The Amazon’s forest area has been predicted to stabilize at 328 Mha from 2030, considering the regrowth and legal cuts of primary forest [28]. However, measures to prevent illegal deforestation in the Amazon and incentives for more efficient production shall be escalated to achieve this. This same study shows that Brazil could double agricultural areas by 2050, compared to 2010 areas, while pastures could significantly decrease, per the adoption of best practices to increase animal productivity [28].

Livestock is the most important land use in the Amazon, appearing in all regions. At the same time, agriculture is concentrated in the southern region of the biome (Figure 5–Amazon), where a set of infrastructure, accessibility, market, and climatic conditions contribute to its development [65,71–73]. Azevedo Junior et al. [65] observed that the supply chain, logistics, technology, labor, knowledge, and capital are uneven between regions of the Amazon biome, leading to the concentration of agriculture in strategic locations. Although the agricultural area is growing, production has outpaced the other areas, showing more efficient land use. However, the values are still well below their potential. This land use class still contributes approximately one-third of deforestation in the Amazon region, mainly linked to the expansion and appreciation of the agricultural sector in other parts of the country [74].

In a general context, pastures in Brazil, especially in the Amazon, are still extensive, with low inputs and a high degree of degradation and, consequently, low yields [75], because production is based on low input demand, neglecting technologies and property management strategies that could increase productivity [76,77]. Those showing higher productivity are usually accompanied by a drastic increase in the use of inputs and capital [78], which is justified by the fact that 76.3% of the Amazonian municipalities have hardly any access to production and market factors, and the ones that do generally choose crops [65].

Although the livestock sector has also shown a higher efficiency in the last 35 years, identified here through the animal stocking rate (Figure 5), this occurred slowly. Regardless of the biome, the animal stocking rate in Brazil is 32 to 34% of its capacity [29].

The production of agricultural commodities is in economies of scale and still subject to an increase in agricultural land in Brazil. Further, extensive production and low efficiency of pastures in the Amazon increasingly pressure the opening of new lands [68,79]. The trend of loss of native forests found in our study calls for new solutions, together with environmental policies, to preserve the biome [62]. Our results support recent calls to prioritize forest protection in promoting sustainable land use in the Amazon [80].

4.1.2. Atlantic Forest Biome

The intensive loss of native forests in the Atlantic Forest began before the historical series analyzed in this study. The economic exploitation of different commodities accompanied the loss of native forest (e.g., Pau-Brasil, sugarcane, coffee, and cocoa) [81,82], in parallel with the expansion of the population, urban-industrial spaces and agricultural borders of the country [83].

Although the area of native forest evidence periods of territorial gains and losses, in the periods with tendencies towards more significant area reductions (1986 to 1991), 75% of the charcoal originated from native forest, leading to more significant deforestation [84].

During the second half of the 20th century and the beginning of the 21st century, the native forest area gain occurred mainly in areas with slopes above 20%, unsuitable for agricultural mechanization, irrigated systems, and livestock [85]. In some Atlantic Forest regions, the old pastures used for milk and beef production contributed about 75% to the new forest areas between 1980 and 2010 [86], which is related to the setting of industrialization, economic development, rural socio-economic crisis, especially in dairy farming due to lower milk price and land degradation by overgrazing, which led to the rural depopulation of the Atlantic Forest, with ensuing abandonment of pastures, followed by forest regeneration [85].

This trend is also associated with reformulated decrees (e.g., Federal Decree No. 0.750 of 1993) [87], which prohibited the cutting and exploitation of disturbed forest remnants and secondary successional areas in early and advanced stages of the Atlantic Forest. In 2006, this decree was updated by Federal Law No. 0.11.428 (Atlantic Forest Law), which introduced new instruments for biome conservation, such as monetary incentives for Atlantic Forest restoration projects [88]. Along with the law, the Pact for the Restoration of the Atlantic Forest, which provides for the restoration of 15 Mha by 2050, also contributed to stabilizing the native forest area [89].

Currently, we can observe a trend of increasing losses of native forest areas due to a weakened national environmental system (SISNAMA) and changes in laws and regulations [90]. A projection made for the Atlantic Forest indicates that, if the loss of young native forests follows the current rates, we will have only 2.3 Mha of new areas by 2030 and, considering the current rate of losses of older and younger native forests, only 0.49 Mha of areas with additional native forests would be expected by 2030 [25].

Despite pasture area losses, this is still one of the main land uses of the Atlantic Forest, in which most of them are under some degradation condition [91]. Generally, there is a lack of pasture management, use of inputs, liming and fertilization [92]. Soil management through burning is still used [93]. The lack of pasture management adopted in this biome triggers high losses of soil, organic carbon, and nutrients, and these practices must be rethought to increase livestock production in these highly weathered and naturally poor soils [93].

The planted forest is a minority percentage of the territory but has gained prominence over these 35 years, with an almost five-fold growth compared to the baseline (1985). The increase in the area of planted forests occurred mainly in pasture areas due to several factors: low milk productivity and milk prices; strict distribution of state credit, mainly agricultural credit, causing producers to look for a new land use alternative; promotion of pulp and paper companies; cost-effective opportunities considering land price and distance from plantations to processing plants; conservationist ideas, such as the introduction of certification in the eucalypts production system for future fiber exports; and shortage of rural workers influenced by the demand for labor in urban centers [85,94,95].

The growth of this class is still recurrent, mainly with the increase in plantations close to the pulp and paper industries [85]. Planting of eucalypts and pine stands out mainly in the south and southeast regions, while eucalypt is used for wood and bioenergy in the northeast [96].

Besides planted forests, the agriculture area almost doubled compared to 1985, which can be explained by the increase in technology and consumer market and improved rural extension program and rural credit to producers [97]. Linked to this, the domestic demand for biofuels led to the expansion of agricultural areas with sugarcane production in the Atlantic Forest [98], expanding mainly in areas of degraded pastures [30,99,100].

When we compare the map (Figure 4—Atlantic Forest) with land use in 2020 and information provided by the IBGE [101] (p. 30), we notice that the areas of most significant expansion with agricultural land (southwest and northwest) coincide with the regions where sugarcane plantations are concentrated. However, we should remember that the Atlantic Forest also stands out in several other cultures, such as planting wheat, rice, corn, soybeans, and coffee (south region); soybeans, citrus, cotton, corn, rice, castor beans and peanuts (southeast region); and fruit growing (northeast region) [96].

In a general context, the Atlantic Forest has suffered variations in the area with native forest for centuries. Historically, these areas are replaced mainly by agriculture and pasture areas [98]. There is a need to increase native forest areas while adopting more efficient agricultural and livestock practices so that the most populous biome in Brazil can follow a path aimed at the environmental, economic, and social fields [27,102].

4.2. Sustainable Land Use

Our analysis showed that areas of native forests are still being lost to other land uses. We also noticed low values of animal stocking rates, indicating inefficient systems [103]. This situation is linked with a lack of property management and often results in the abandonment of large areas [104], with the loss of native forests as a consequence [105].

This fact can be explained by the economic theory of land use proposed by Von Thünen, who mentions that the land is intended for use that gives the best economic income [106]. Thus, if the land use change and practices developed in a given area provide greater profitability, they are expected to expand at the expense of less profitable uses [107]. In this sense, the efficient use (or the intensification) generally only occurs where land is a scarce factor [108], in which the farmer will not have other opportunities.

As an example, producers seek immediate profit by associating the availability of native forest as an opportunity to expand the area with greater financial profitability. However, Brazil has enough open land to increase future agricultural production, preserving native forest lands [29], as long as it considers high productivity through intensification and sustainable land use, from the recovery of abandoned or poorly degraded pastures [109,110].

Sustainable intensification aims to increase agricultural and livestock production and economic returns, per unit of time and area, minimizing negative impacts on soil and resources and the integrity of the associated non-agricultural ecosystems [34,111,112]. Until 2050, beef production could increase by 20%, crop yields by 88% and wood production by 220% in the Amazon, with the recovery and intensification of degraded and unproductive areas [113].

The diversification of plant species must occur in the intensified strategies to jointly promote environmental, social, and economic benefits [33,110]. Therefore, the low-carbon technology called Integrated Crop-Livestock-Forest (ICLF) reflects this scenario, as it presents livestock, agricultural, or forestry activities in the same area, in rotation, consortium, or succession, seeking synergistic effects between components, considering environmental suitability and economic feasibility [114].

It can be classified in different modalities, resulting in a several possible models, as the ones with the forest component, also called agroforestry systems: Integration Crop-Livestock-Forest (ICLF), or agrosilvopastoral; Integration Livestock-Forest (ILF), or silvopastoral; Integration Crop-Forest (ICF), or silvoagricultural integration; and the one without the forest component: Integration Crop-Livestock (ICL), or agropastoral [114].

The several advantages of the ICLF modalities are already well defined, such as their positive synergistic effects on the soil's physical, chemical, and biological properties that mitigate degradation compared to the exclusive land use strategies [115]. They protect the soil against erosion, mainly on slopes of the Atlantic Forest, which are subject to intense rainfall in the rainy season [116]. They also improve nutrient cycling, with uptake at greater soil depths [117] and agricultural income [118].

Pasture benefits could be even more significant, such as increasing animal support capacity [119,120] by up to 52% of its potential [29]. Increased animal production is associated with thermal comfort provided by the moderate shading of the tree component [121–123], improved annual animal weight gain, and increased forage longevity [116]. It increases land use potential and becomes an alternative to increase property revenue in the dry season [110,121–123]. We observed a 28% increase in animal weight gain and a 23% increase in forage production [124].

This technology also can mitigate environmental impacts by increasing soil carbon stocks and reducing greenhouse gas emissions [34,125]. The conversion of 20% of unproductive areas in the world with ICLF strategies could potentially mitigate 3.4 ± 1.7 × 109 t CO_2eq year^{-1} [126].

In the Amazon, greater market competitiveness, increased productivity, improved pasture, increased income, greater adaptability, and reduced risk were identified by a small portion of farmers that adopted ICLF [77]. Generally, the ICL strategy in the Amazon region is implemented from October to February in soybean cultivation in a part of the farm, while the remaining area is used for cattle maintenance. After the soybean harvest, the whole farm area is used for livestock production from March to September [127]. Adopting integrated strategies with trees is still scarce in that region, and it can occur with the afforestation of pastures with native tree species (originating from natural regeneration). However, exotic species, such as teak (*Tectona grandis* L.f), African-mahogany (*Khaya ivorensis* A. Chev.), and eucalypt (*Eucalyptus* sp.), are used in most cases [128].

In the Atlantic Forest, the intensification to increase income generation, diversify production, and increase the quality and productivity of the land are recognized by producers that adopt the ICLF [129]. In this biome, the ICL strategy is adopted to recover pastures and an alternative for animal feed in the restrictive period of rainfall of the year, with beans, corn, rice, sorghum, soybean, millet, and sunflower as the main crops [130]. The main species used for ICLF in that biome is also eucalypt, mainly because of its rapid growth and easy management [130,131]. ICLF-derived eucalypt wood is used for construction activities in the farm or sold to sawmill companies. It has a potential sequestration C rate of 17 Mg CO_2eq ha^{-1} y^{-1} in its biomass [132].

A study developed by Maia et al. [133] shows that sustainable strategies have a positive impact on the Atlantic Forest when related to animal stocking rate and agricultural production per hectare, observing an increase of up to 0.5% in the mean number of animal heads per hectare in each area percentage increased with these systems. These authors did not observe significant impacts for the Amazon, justified by the predominance of extensive livestock.

Sustainable land use was encouraged by various programs and public policies over time. In the Amazon, we could mention the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) [56]; Sustainable Amazon Plan [134]; Sustainable Regional Development Plan for the Area of Influence of BR 163 [135]; Public Forest Management Law [136]; Amazon Protected Areas Program (ARPA) [137]; and, more recently, Amazon Plan 2021/2022 [138]. In the Atlantic Forest, examples include Atlantic Forest Law n° 11.428/2006, including the Municipal Plan for the Conservation and Recovery of the Atlantic Forest (PMMA, 2022) [88], and Biodiversity and Climate Change Project in the Atlantic Forest [139].

At the national level, the ICLF is encouraged by public policies, such as the Low Carbon Emission Plan in Agriculture (Law n° 12,187/2009), which is a guideline for the use of technologies to increase agricultural productivity and promote the reduction of GHG emissions through changes in the production process [140]. Moreover, the National Crop-Livestock-Forest Integration Policy (Law n° 12.805/2013), which aims to improve productivity, product quality and income from agricultural activities, by implementing ICLF strategies in already deforested areas [141].

Although the ICLF is a large-scale alternative to promote the adoption of low-carbon agriculture, with all its recognized benefits of reducing the environmental impacts of food production and creating greater resilience in the food system [142], its adoption is a significant change in production techniques [21], mainly in the Amazon and Atlantic Forest, with already culturally determined land use. Thus, there are many barriers to overcome in these biomes for ICLF adoption to reach its full potential.

4.3. Barriers for the Adoption of ICLF Strategies in the Amazon and Atlantic Forest

While the ICLF benefits are reported in the scientific literature, this strategy has not been widely adopted. It is projected that the four modalities of ICLF strategies in Brazil will represent 17.42 million hectares in 2020 (in all the five biomes) [143].

Looking regionally, in the Amazon and Atlantic Forest, we also notice this slow pace of adoption when we compare data from the 2006 Agricultural Census [144] and 2017 [145] of the total number of ICLF implemented.

In the Amazon biome, over these 11 years, there was a total increase of 6% in areas with ICLF, from 1.51 Mha (2006) to 1.61 Mha (2017) [144,145]. This represented 2.65% of the total area of pasture and agriculture (60.35 Mha–Figure 2A) in 2017. When we look at the Atlantic Forest, in the same period, the increase in new areas with ICLF implemented was 25%. The ICLF, which previously occupied 1.26 Mha (2006) in this biome, now covers 1.57 Mha (2017) of the territory [144,145], representing then 3.27% of the total area of pasture and agriculture (47.97 Mha–Figure 3A) in 2017.

Greater acceptance of sustainable systems in the Atlantic Forest may be linked to more accessible access to credit in this biome [146] and more intensive use of capital, technology, and skilled labor [133]. However, this growth is still considered low, and some studies have been carried out in order to understand the barriers behind this slow adoption process.

In the Atlantic Forest, limitations focus on uncertainty about the system, reduction in the yield of the leading agricultural crop, and lack of models and knowledge in the region [129]. Furthermore, there are bureaucratic barriers and legal uncertainties regarding the use and sale of native trees in the biome, favoring the adoption of exotic species [10,147].

As much as there is a trend towards sustainable scale-up, some producers still guide their decisions only by the transient profitability of the system, preferring conventional systems. What hampers the implementation of other systems is the lack of information and technical assistance to create a culture of sustainable production in the Atlantic Forest [8]. It is necessary to improve technical assistance, rural extension, capacity building, and training, mainly to encourage those who use conventional agriculture and successful examples to facilitate the opportunity of these producers [129].

The main barriers identified in the Amazon are related to access to credit, land tenure, infrastructure, rural education, skilled labor, and existing cultural traditions

[77,133]. The way to use agricultural land more sustainably in the Amazon must start with improving the distribution of rural credits with competitive and sustainable credit lines; knowledge transfer, which raises awareness of high-performance technologies; direct and long-term support to producers through rural assistance and extension; and incentive through market signals [77,148,149]. We should highlight the importance of governmental, cultural, and ecological structures to influence the environmental perception of these producers [77].

Technologies must be available and accessible so that the ICLF is widely adopted, and this will occur through a set of strategies that will involve an integrated management process, the sustainability of the use of natural resources, finances, human resources, and the competitive market [150–152]. New Technological Reference Units (URT) must be included in strategic locations, by research centers (e.g., Embrapa), universities, and regional programs, with targeted models, to achieve these strategies. The area of influence and the profile of the target producers must be evaluated [153]. The ABC Program credits, the main line of credit for sustainable development, which includes implementing ICLF strategies, should be less bureaucratic, with adjusted interest rates, favoring their demand [154]. Besides, there is a need for greater dissemination of this credit plan between producers [148,155] and training of bank managers.

It is mainly necessary to formulate policies with government actions and research institutions that incorporate environmental sustainability and organizational and technological innovations accessible with locally based initiatives [102,156,157].

5. Conclusions

In the Amazon, the expansion of pastures is still the leading cause of losing native forest areas. Agriculture has also expanded at the expense of these forests. Over the 35 years analysis (1985 to 2020), 44.53 Mha of native forests were lost so that new areas of pasture (38.10 Mha) and agriculture (6.06 Mha) emerged. Areas with planted forests are still minorities in this biome. In the Atlantic Forest, areas of 0.99 Mha of native forests and 11.53 Mha of pastures were reduced, being replaced by 8.06 Mha of agriculture, and 2.99 Mha of planted forest.

The animal stocking rate in the pastures has increased over these years, albeit at a slow pace, which is because pastures are still extensive, without proper management, favoring soil degradation, reducing productivity, and expanding the opening of new frontiers in areas of native forest, especially in the Amazon, where this production model predominates.

These land uses are essential for economic development and food production in the country. However, they should be managed in a planned fashion, emphasizing sustainable practices. In this context, the ICLF emerges as a promising strategy, with several benefits reported in the scientific literature (e.g., increased productivity, economic viability, and environmental gains). Nevertheless, we observe that the adoption of this strategy in the Amazon and Atlantic Forest is still incipient.

Public and private policy actions should consider local and regional aspects, aiming at incentives and programs focused on adopting ICLF. In this sense, technical assistance and rural extension must be strategic in the Amazon, combined with actions to promote rural credit and regional infrastructure. In the Atlantic Forest biome, actions should be concentrated on technology transfers, aiming to reduce producers' uncertainties and the bureaucracy of laws for the sustainable use of resources/native forest species in these systems.

The approaches presented in this article reiterate the promising opportunity of the ICLF to replace exclusive uses of pastures and agriculture in conventional models. This strategy is also aligned with the ABC Plan Policies, which aim for sustainable land use to increase agricultural productivity and reduce GHG emissions.

The adoption of ICLF strategies can boost the preservation of these biomes, which have abundant natural resources. The Atlantic Forest biome has been impacted by significant losses of native forest areas over many years and currently has significant areas with low productivity, with potential for recovery and production through the implementation of these systems. The Amazon still has an immense area of native forest and can reconcile preservation with the recovery of degraded and abandoned areas, thus avoiding the setting of deforestation in the Atlantic Forest. The ICLF can strengthen the country's agriculture and economy, contributing to global food security, promoting the recovery of environments in the Atlantic Forest biome, and avoiding the devastation of the Amazon.

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Chapter 2 – Characteristics and perceptions of rural producers who adopt low-carbon technologies in the Amazon

1. Introduction

The Amazon region has the largest extension of tropical forest in the world, with a high biodiversity that provides important ecosystem services at a local and global scale, such as climate regulation, hydrological and biogeochemical cycles, and provision of forest products that benefit humans [1–4]. In addition, Amazon Forest has a significant impact on mitigating greenhouse gas (GHG) emissions, particularly in carbon storage in above- and below-ground biomass [5,6]. However, about 44.53 Mha of native forest was lost to deforestation from 1985 to 2020, with significant increases during the period 2019 and 2020 [7].

One of the main causes of deforestation in the Amazon is the opening of new areas for the expansion of areas with pastures and agricultural crops [7–9]. This happens because livestock production systems are extensive, characterized by low animal stocking rates, low use of inputs, low management intensities and productivity, resulting in a high degree of degradation of pastures and low yields [10]. Furthermore, deforestation and degradation of native forests increases the emission of GHG and the loss of carbon stocks [5,6]. Despite this, the remaining forest fragments are important reservoirs of biodiversity and ecosystem services, especially in carbon storage in tree communities, and therefore the importance of conservation areas within rural and indigenous properties [5,11,12].

The challenge of preserving the Amazon can only be overcome with changes in production systems and sustainable rural development policies that encompass the economic, environmental and social spheres [13–15]. In this sense, agroforestry systems (AFS) have aroused interest in agricultural development policies in Brazil [16]. These systems combine, in the same unit of area, forest species (trees, shrubs, palms, bamboos, etc.) with agricultural crops and/or the presence of animals, to offer goods and services on a sustainable basis [17,18]. Increased productivity and income are among the recognized economic benefits of product diversification [19–23]. In addition, the technology improves the sustainability of production by sequestering carbon, provides animal welfare with tree shade, conserves water and soil, recycles nutrients, preserves ecosystem services, and increases animal stocking rates [24–27].

The interest of policies in this system occurs due to the great variability of possible arrangements, which can meet different financial, soil and climate conditions, producer purposes and system function, and can serve for protection and production, in addition to self-consumption and/or commercial production [17,18]. Even though some authors consider that this use has grown since the 1980s [28], we realize that in the Amazon this is not a reality, even with various incentives through programs and policies (e.g. Action Plan for the Prevention and Control of Deforestation in the Legal Amazon [29], Sustainable Regional Development Plan for the Area of Influence of BR 163 [30]; Public Forest Management Law [31]; Amazon Protected Areas Program [32]; and the Amazon Plan 2021/2022 [33]). In a period of 11 years, there was an increase of only 6% in areas with AFS in this biome, with a total of 1.6 Mha [34].

The literature shows that, for an increase in the adoption of these systems, there is a need to bring the issue of climate change closer to agricultural production and improve the transmission of information and training, especially for small and medium producers [35,36]. The lack of information and technical assistance to producers is one of the major problems for more sustainable practices to be adopted. In addition, financial incentives, such as rural credit, are also an obstacle to the adoption of these technologies, mainly to cover the initial implementation costs [37–39].

The effective inclusion of small producers and traditional communities in sustainable rural development can be done through the strengthening of public policies and projects to expand production systems based on biodiversity and low-carbon agriculture [40,41]. Projects for the implementation of low carbon agriculture technologies aimed at small producers for the sustainable development and recovery of degraded areas are essential in the fight against climate change [36,39,41].

However, the effective success of projects for real future impacts in the dissemination of technology, depends on the producers' conviction that it is necessary, possible and sustainable (economically, socially and environmentally) to change their practices on the rural property [42]. This becomes essential for the dissemination of good agricultural practices, mainly because many producers are motivated by neighboring producers to adopt [43]. In view of this and the evidence of the persistence of livestock in the Amazon, there is a need to better understand the characteristics of producers and perspectives on land use, whether for a particular livestock or a diversified system. Despite the wide recognition and intense political interest in the problems associated with livestock [44], the profile of properties and producers that adopt better management practices, as well as the impact of technologies on their lives, have been relatively little explored.

Understanding these factors is important so that more targeted interventions and public policies can be developed and applied to Amazonian producers [38,45,46]. It is also an opportunity for negotiation and engagement for municipal institutions to formulate, together with landowners, voluntary land management protocols that stipulate forest conservation objectives [47].

In this context, we consider three objectives in this study: to describe patterns of sustainable land use by small and medium rural producers in the Amazon biome, considering agroforestry systems and managed pasture monoculture; characterize rural producers who adopt these technologies and; verify the benefits of this use from a producer's perspective. This study seeks to overcome this knowledge gap by evaluating small and medium-sized producers in three important states in the Amazon for the agricultural sector. It will be represented by Mato Grosso, Pará and Rondônia, which together represent 57% of the agricultural Gross Domestic Product of the Legal Amazon [48]. As they are states dependent on this sector, they may suffer significant impacts in the face of climate change and become important in strategies aimed at agricultural sustainability [48].

For this, we first report the main technologies adopted in each state, as well as the characteristics of these properties and technologies. Subsequently, we identified the socioeconomic profile of these producers and the management of the system adopted by them. To complement this, we analyzed how producers are interpreting the benefits of adopted practices and social projects for local strengthening, in a perspective that considers life experience, knowledge of practices and perception of the place produced. Finally, we discuss factors that may be associated with the choice of system.

2. Material and Methods

2.1. Description of the project under study

This study was developed within the scope of the Sustainable Rural Project Phase I (SRP I) - Low Carbon Agriculture Project. This project was prepared in the form of a technical cooperation (BR-X1028), with funding from the International Climate Fund (ICF) and Department of Environment, Food and Rural Affairs of the Government of the United Kingdom (DEFRA) of USD 39,200,000 for various actions to promote to sustainable development in the Amazon and Atlantic Forest [49]. The Brazilian Ministry of Agriculture, Livestock and Supply (MAPA), through the Secretariat of Social Mobility, Rural Producers and Cooperativism, was the beneficiary of the project, which had the Inter-American Development Bank (IDB) as executor and financial manager [50]. The Brazilian Institute of Development and Sustainability (IABS) was the institution selected to carry out the services of execution and operationalization of administrative and logistical activities of the Sustainable Rural Project and the Brazilian Agricultural Research Corporation (Embrapa) the scientific coordinator of the project [51].

The main objective of SRP I was to promote sustainable rural development by promoting the implementation of low-carbon technologies in small and medium-sized rural properties (according to the fiscal module1F[2]) in the Amazon and Atlantic Forest, aiming at potential strategies for reducing poverty, conserving resources and biodiversity, and protecting the climate. The municipalities in these biomes were selected considering criteria such as: priorities for protecting the environment, responding to the climate, promoting renewable energy and food security; presence of economic and social infrastructure and other public or private professional advisory services that offer attractive conditions for producers to invest profitably in the implementation of technologies; market conditions for agricultural, livestock and forestry products favorable to rural producers and with attractive prices; commercial availability at competitive prices of inputs for the implementation of technologies and; presence of industries or other large consumers of forest inputs interested or active in vertical integration with the rural producer [54].

The activities carried out by the project started in 2013 and ended in 2019 and had actions aimed at financial and technical support to rural producers in the implementation of low-carbon technologies; technical support to rural producers and technical assistance agents; and implementation, management, monitoring and evaluation of technologies [50]. Producers interested in implementing low-carbon technologies on their rural properties should participate in a public notice (Call for Multiplier Units[3]), together with a technical assistant approved by the project, and submit a technical proposal for the implementation of technology [55]. For this, they had to meet criteria

[2] The fiscal module is different for each municipality. Law nº 6.746/1979 [52] defines that the number of fiscal modules of a rural property will be obtained by dividing its total usable area by the fiscal module of the Municipality. The classification of rural properties is present in Law nº 8.629/1993 [53], being, among several criteria: small property that property with an area comprised up to 4 fiscal modules; medium property, rural property with an area greater than 4 and up to 15 fiscal modules and; large property, the property with an area of more than 15 fiscal modules.

[3] Multiplier Units - MUs, were considered rural production areas where one or more of the promoted technologies and environmental regularisation activities would be implemented.

that ranged from regularized land and the non-commitment of environmental crimes, to the regularized status of the producer's individual registration. It also involved producer size and annual gross agricultural income. The criteria can be verified in detail in the “Operational Manual of the Low Carbon Agriculture Project and Avoided Deforestation to Reduce Poverty in Brazil BR-X1028” [54] and in the call for Multiplier Units [55].

The implementation proposals were approved by a team of technical reviewers responsible for Embrapa. Producers and technical assistants signed a technical cooperation agreement with the project to define the obligations, terms, conditions and rights of the parties regarding the adoption of low-carbon technology on the farmer's property within the scope of the project [56]. Producers had obligations such as conserving the forest and implementing low carbon technology in accordance with the terms approved in the technical proposal. Those producers covered by the SRP I, as well as their families, were granted several benefits, such as: training on topics related to low-carbon technologies; workshops for female empowerment together with encouraging the inclusion of young people in rural areas; technical assistance and constant rural extension and; financial resource support. Other obligations and benefits can be verified in the technical cooperation agreement [56] and in the BR-X1028 project signed by the IDB [49].

On average, R$ 10,400.00 was allocated to each area with low-carbon technology implemented. The benefits were proportional to the area to be implemented. An additional financial incentive of R$ 1,869.00 was also allocated, on average, for producers approved in the “Support program for the acquisition of seedlings and inputs” to acquire seedlings and inputs necessary for the implementation of low-carbon technologies [51]. As it is a non-reimbursable financial support, accountability was unnecessary, since the commitment was seen through the results verified in the properties. The resource was transferred through the Bank of Brazil. Details about the project can be verified in the study by Newton et al. [42] or on the websites *http://mata-atlantica-amazonia.ruralsustentavel.org/* and *https://www.iadb.org/en/project/BR-X1028*.

All producers who participated in the project were in accordance with item 9.0 “Privacy Conditions” of the Call for Multiplier Units [55], in which:

> *“Participants are responsible for the content and veracity, as well as accepting that the information*

> *passed on may be used by the project for the purpose of monitoring and evaluating results".*

In addition, all participants signed the Technical Cooperation Agreement [56], in which:

> *"They express their consent so that the information and other data collected during the execution of the planned activities can be freely used by the executor and financial manager of the project".*

2.2. Description of the study area

This study included the Amazon biome, considered part of SRP I. The 30 municipalities were divided between the states of Mato Grosso (MT), Pará (PA) and Rondônia (RO). In Mato Grosso, the municipalities covered were concentrated in the north of the state, including: Alta Floresta, Brasnorte, Cotriguaçu, Juara, Juína, Marcelândia, Nova Canaã do Norte, Querência, Sinop and Terra Nova do Norte. This state has 72% of establishments located in areas between 10 and 500 ha, with only 14% receiving technical guidance [57]. It has a total of 69% of establishments included as family producers, in which only 13% receive technical guidance [57].

In the state of Pará, the study municipalities were: Dom Eliseu, Ipixuna do Pará, Marabá, Medicilândia, Paragominas, Rondon do Pará, Santana do Araguaia, Thailand, Tomé Açu and Tucumã. They were concentrated in the eastern region, with one municipality in the southwest region and another in the central region. Here, 59% of establishments are between 5 and 200 ha, where technical guidance only reaches 6% [57]. A total of 85% of the establishments in Pará are represented by family producers, with 5% receiving technical guidance [57].

In Rondônia, the study was carried out in the central, northeast and southeast regions, formed by the municipalities: Alta Floresta D'Oeste, Ariquemes, Buritis, Cerejeiras, Governador Jorge Teixeira, Machadinho D`Oeste, Parecis, Rolim de Moura, Santa Luzia D `West and Theobroma. Rural properties are located mainly between 5 and 200 ha, where technical guidance reaches 18% of them [57]. A percentage of 81% of establishments in this state are represented by family producers, with 17% receiving guidance, respectively [57].

The location of the municipalities is shown in Figure 1, Results section.

2.3. Research approach

The interviews were carried out at the time of development of the technical proposal for the implementation of one of the low-carbon technologies supported by the Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low-Carbon Economy in Agriculture (ABC Plan) [16]. This yielded a rich dataset with 1,420 producers.

However, for this study, two types of low-carbon technologies defined in the ABC Plan were considered:

- Agroforestry System (AFS) – integrates forestry, agricultural and/or livestock components in the same area, in intercropping, succession or rotation. It could be implemented in the following modalities: agrosilvopastoral or crop-livestock-forestry integration (ICLF); silvopastoral or livestock-forestry integration and; agroforestry or crop-forest integration. We did not separate the modalities and everything was addressed as AFS. The SRP I addressed this technology as "ICLF"
- Managed Pasture Monoculture (MP) – aimed at recovering degraded pastures with the aim of reversing the situation of low productivity and not diversifying the system. It could be carried out directly, without replacing the forage species, or through indirect recovery, using pasture or planted annual crop as an intermediary in the recovery process [58]. SRP I addressed this technology as "RDA-P" (recovery of degraded areas with pasture).

2.3.1. Characterization of the profile of producers and rural properties

The interviews were guided by a set of semi-structured questions in order to understand the profile of the farmers and rural properties. The questions were structured from a series of meetings with stakeholders, to design a robust approach that would gather data in a comprehensive and reliable way and that allowed to understand the local situation of properties and producers for follow-up after the project of the agriculture of low carbon emission. The technique used was a participatory diagnosis, which allowed the assessment of the situation, the reality of the territory and the social groups.

The characteristics of the property and rural producers were structured into three categories, as shown below.

1- Characteristics of the property and technology adopted: to assess information on the property, quantitative data were collected on the total size of the rural property and the size of the area with the technology adopted. In addition, the size of the forest conservation[4] area was identified to determine the conservation attitude of these producers. This information was captured from the georeferencing of the area and also verified from the Rural Environmental Registry (REG) of those producers who had that registration.

The annual gross agricultural income of the producers was structured in classes, as a way of measuring the resources available for the adoption of a new technology, for example. The classes were: less than or equal to R$ 1,760,000.00; greater than R$ 20,000.00 and less than or equal to R$ 360,000.00 and; less than or equal to R$ 20,000.00. From this, the producers were classified into: medium producers, with modules between 4 and 15 and annual gross agricultural income less than or equal to R$ 1,760,000.00 (type M); small producers, with module less than or equal to 4 and annual gross agricultural income greater than R$ 20,000.00 and less than or equal to R$ 360,000.00 (type P1) and; small producers, with module less than or equal to 4 and annual gross agricultural income less than or equal to R$ 20,000.00 (type P2).

On the property, qualitative information was also collected regarding the activity developed in the area before the implementation of the low carbon emission technology and practices that should be carried out on the properties for the purpose of environmental adaptation, such as restoration of riparian forest, restoration of legal reserve, protection of springs, granting water and recovery of degraded areas. In our study, we will only address the recovery of degraded areas, because, to discuss the others, it would be necessary to identify other information on the property that was not captured. For example, to know if the proportion of producers who need to restore the riparian forest is high or not, we would need to identify the number of properties with rivers, lakes and springs.

The main species implanted in the systems were identified and reported, without a separation by the type of component (crop, livestock and forestry) or identification of arrangements structure. This is because the information regarding the species was not rigorous, due to the lack of knowledge of regional diversity. However, producers seek

[4] Within the scope of the SRP I, forest conservation was defined as a forest fragment containing representative species of the biome, in order to guarantee the quality of its functions regarding the conservation of the biome and the protection of the climate and biodiversity. It could be composed of a Permanent Preservation Area (PPA) and/or Legal Reserve (LR). Protected area, covered or not by native vegetation, with the environmental function of preserving water resources, the landscape, geological stability and biodiversity, facilitating the gene flow of fauna and flora, protecting the soil and ensuring the well-being of populations human rights" (Law nº 12.651/2012, Art. 3rd item II [59]). Area located within a rural property or possession [...] with the function of ensuring the sustainable economic use of the rural property's natural resources, assisting the conservation and rehabilitation of ecological processes and promoting the conservation of biodiversity, as well as the shelter and protection of wild fauna and native flora" (Law nº 12.651/2012, Art. 3rd item III [59]).

to report the main species of economic interest within the system. With this, we identified the genus and, when possible, the species by the Flora of Brazil [5]system. The purposes of the species in agroforestry systems were also informed by the producers. We do not highlighted the purpose of the MP species as they are intended exclusively for animal use. The list with the number of observations for each species and the purpose will be available in the appendix of this chapter.

2- Socioeconomic characteristics: for the socioeconomic assessment, qualitative information about the producer was identified, such as: gender; marital status; education level; place of residence; workforce on the property; whether technical assistance was received (prior to SRP I); main economic activity within the property; whether they had access to rural credit, family allowance and retirement; whether the property was registered in the REG and; whether they were affiliated with rural producers' unions. Quantitative data such as age; time of experience with rural production; number of family members who collaborated in the production and; the number of paid people who collaborated in the production.

3- Management practices in function of the implanted technology: in order to verify the intensity of management necessary for each one of the implanted technologies, it was identified, qualitatively, if the producers carried out the control of undesirable species, soil fertilization, soil correction before planting, rotational management, chemical products and irrigation were used.

Subsequently, the information was combined and organized ensuring as much completeness and accuracy as possible in the circumstances.

2.3.2. Producers' perception of the technologies adopted

The present study also evaluated the perceptions of the producers about the impacts of the implanted technologies. We consider the qualitative information collected, from positive or negative responses, about:

- Knowledge about low carbon agriculture.
- Benefits for the producer and property: improvement in income, productivity, job creation, environmental quality of the property and generation of opportunities for women and young people.

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[5] Flora and Fungus of Brazil: discloses morphological descriptions, identification keys and illustrations for all species of plants, algae and fungi known to the country. Flora and Fungi of Brazil: discloses morphological descriptions, identification keys and illustrations for all species of plants, algae and fungi known to the country. Visit Flora and Fungi of Brazil, Rio de Janeiro Botanical Garden, at: < http://floradobrasil.jbrj.gov.br/>.

- Satisfaction with the technology adopted: whether the technology will continue to be adopted in the same area, whether it intends to increase the area with the same technology and whether it intends to implement other sustainable technologies.
- The main contributions to the region: identified new productive opportunities for the region, improvement of the environmental quality of the region and if it was verified the improvement in the fight against climate change.
- Contributions from social projects (in this case, the SRP I) for the region: whether there was a strengthening of local associations or cooperatives; improvement in the technical level of producers and improvement of technical assistance.

This evaluation was carried out at the end of the project (2019) through a new on-site visit, in a new structured questionnaire.

2.4. Data analysis

Descriptive statistics were applied to each category analyzed, as well as for the final impact assessment. The mean values, standard error, maximum and minimum values of the quantitative variables were estimated. The normality and distribution of continuous quantitative data (e.g., total areas of properties, area of implanted technologies and area of forest conservation) were verified using the Shapiro-Wilk test and the Q-Q graphs [60]. Thus, the tests reveal that the data do not meet the assumption of normality and therefore were compared using non-parametric statistics [60]. Thus, the Wilcoxon test was used to compare technologies (MP x AFS) within the same state and the Kruskal-Wallis method to compare samples of the same technology in different states [60]. After the Kruskal-Wallis test, Dunn's test of multiple comparisons was performed to verify the states that differ, considering an alpha of 0.025.

3. Results

3.1. Profile of producers and rural property

3.1.1. Adopted technology and general characteristics of the property

Of the 1,420 rural producers identified that implemented low-carbon technologies, 1,300 implemented MP and AFS, while the other 120 producers implemented technologies such as forestry monoculture and native forest management, which we will not address here in this study.

Agroforestry and pasture monoculture systems were identified in 28 of the 30 municipalities that were part of the study area (Figure 1). Querência and Sinop, located in the state of Mato Grosso, were the two municipalities that did not have these technologies implemented. In Mato Grosso, it is possible to observe the concentration of MP in all municipalities, with AFS being represented only in Cotriguaçu and in very small proportions in Nova Canaã do Norte. In Pará, the municipalities of Ipixuna do Pará, Rondon do Pará and Santana do Araguaia were exclusive with MP, while Dom Eliseu and Tomé-Açu were exclusive with AFS. In Rondônia, the AFS was concentrated mainly in the northeast and central region of the state, while the MP was concentrated in the southeast region.

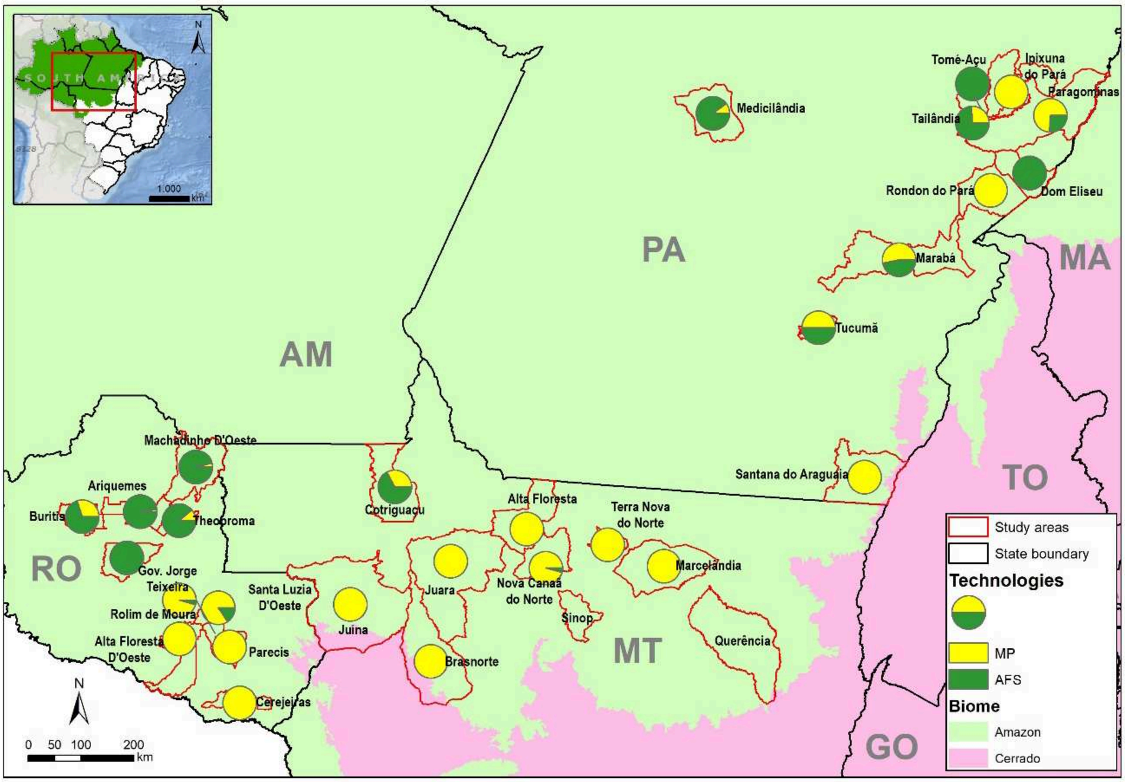

Figure 1. Distribution of AFS (agroforestry system) and MP (managed pasture monoculture) technologies by municipality, in the states of Mato Grosso (MT), Pará (PA) and Rondônia (RO).

Among our interest group (1,300 producers), MP is the main technology deployed by most of the surveyed producers (70%) and represents the largest total areas (16,351 ha) and average deployment (18 ha $\pm$ 0.2) [Table 1]. This technology ranks first in terms of adoption by the surveyed producers in Mato Grosso (91%) and Pará (58%), with Mato Grosso having, on average, the largest implanted areas (19 $\pm$ 0.2). In Rondônia, AFS is the main technology adopted (54%) by respondents, although the largest total and average areas implemented are MP (Table 1). The areas of AFS technologies differ across states ($p < 0.05$) [Table 1 and Figure A1 AFS – Appendix]. The AFS in Mato Grosso has larger technology areas than in Pará ($p < 0.025$), but the same as the AFS technology areas in Rondônia ($p > 0.025$). The AFS area in Pará is the same as in Rondônia ($p > 0.025$) [Table 1 and Figure A1 AFS – Appendix]. The MP also differs between states ($p < 0.05$), with larger areas of implantation in Mato Grosso than in Pará ($p < 0.025$) and in Rondônia ($p < 0.025$) [Table 1 and Figure A1 MP – Appendix].

Almost all the surveyed producers are small (99%) and only a portion of 1% is represented by medium producers. Without exception, all the medium-sized producers have implemented MP technology. Other interviewees who implemented MP were concentrated mainly in the P1 type (86%), that is, small properties with higher gross agricultural income (between R$20,000.00 and R$360,000.00). Meanwhile, producers who adopt AFS are distributed among small types P1 (68%) and P2 (32%), with higher agricultural income (between R$20,000.00 and R$360,000.00) and lower (less than R$20,000.00), respectively (Table 1).

In the largest areas of property (average 72 ha $\pm$ 2.4) the adoption of mainly MP was identified. On the other hand, producers with smaller areas of property (average 48 ha $\pm$ 2.1) mainly implement the AFS. In Mato Grosso, producers that adopt MP and AFS have, statistically, the same size of the total area of the property. In other states, the AFS is always lower. The average area of property of AFS respondents did not differ by the Kruskal-Wallis method ($p > 0.05$) [Table 1 and Figure A2 AFS – Appendix], but by Dunn's test of multiple comparisons, the area of property of the AFS producers in Mato Grosso is marginally higher than for producers in Pará ($p = 0.027$) [Table 1 and Figure A2 AFS – Appendix]. The area owned by MP producers differs ($p < 0.05$) only between producers in Pará and Rondônia ($p < 0.025$) [Table 1 and Figure A2 MP – Appendix].

Even though the areas of properties are on average larger for MP, forest conservation areas in terms of hectare are statistically equal between MP and AFS producers in the three states.

Table 1. Technology adopted and characteristics of the property in the states of Mato Grosso, Pará and Rondônia.

Characteristics	Mato Grosso (N = 574)		Pará (N = 420)		Rondônia (N = 306)		Total by technology (N = 1,300)		Total of the study (N = 1,300)
	MP	AFS	MP	AFS	MP	AFS	MP	AFS	
Technologies adopted									
N	524	50	244	176	140	166	908	392	1,300
%	91	9	58	42	46	54	70	30	100
Area of adopted technology (ha)									
Average ± SE	19 ± 0.2	15 ± 1.3*	17 ± 0.5	11 ± 0.5**	16 ± 0.5	12 ± 0.4**	18 ± 0.2	12 ± 0.3	16 ± 0.2
Min. e max.	[2–39]	[1–42]	[1–56]	[1–25]	[2–31]	[2–24]	[1–56]	[1–42]	[1–56]
Total area	10,008	727	4,072	1,881	2,272	1,993	16,351	4,601	20,952
Producer type (%)									
Small P1	98	80	65	76	81	55	86	68	81
Small P2	2	20	32	24	17	45	12	32	18
Medium (M)	0	0	3	0	1	0	1	0	1
Rural property area (ha)									
Average ± SE	72 ± 3.1	70 ± 10.4ns	77 ± 5.3	46 ± 2.6**	61 ± 4.6	45 ± 2.7**	72 ± 2.4	48 ± 2.1	65 ± 1.8
Min. e max.	[9–679]	[9–314]	[18–816]	[7–225]	[10–423]	[7–263]	[9–816]	[7–314]	[7–816]
Total area	37,957	3,517	18,744	8,063	8,560	7,410	65,260	18,990	84,250
Forest conservation area (ha)									
Average ± SE	16 ± 1.4	20 ± 4.6ns	15 ± 1.3	12 ± 1.0ns	13 ± 1.3	14 ± 1.2ns	15 ± 0.9	14 ± 0.9	15 ± 0.7
Min. e max.	[0–446]	[0–133]	[0–202]	[0–107]	[0–96]	[0–126]	[0–446]	[0–133]	[0–446]
Total area	8,187	1,016	3,772	2,170	1,850	2,303	13,809	5,489	19,298
Proportion of technology area in relation to the total area of the property (%)									
Average	43	35	29	30	36	33	38	32	36
Min. e max	[3–96]	[0.3–94]	[1–95]	[2–88]	[1–92]	[0.1–91]	[1–96]	[0.1–94]	[0.1–96]
Proportion of forest conservation area in relation to the total area of the property (%)									
Average	16	22	22	29	21	28	18	28	21
Min. e max.	[0–84]	[0–70]	[0–92]	[0–88]	[0–75]	[0–76]	[0–92]	[0–88]	[0–92]
Activity developed in the area before the implementation of low carbon technology (%)									
Livestock	97	84	88	44	95	68	94	59	84
Agriculture	0	4	0	22	0	19	0	18	5
Forest	2	8	5	6	4	9	3	8	5
Others	0	4	7	28	1	4	2	15	6
Recovery of degraded areas for environmental adequacy purposes (%)									
No	19	22	55	51	27	42	30	43	34
Yes	81	78	45	49	73	58	70	57	66

AFS: agroforestry system; MP: managed pasture monoculture. “N” means the number of observations performed. “SE” means the standard error of the mean. “Min. and max.” mean the minimum and maximum value, respectively, found. Wilcoxon test **P<0.001, *P<0.01, ns (no significant differences).

Forest conservation areas are also the same among AFS producers in Mato Grosso, Pará and Rondônia (p = 0.03) [Table 1 and Figure A3 AFS – Appendix]. On the other hand, the forest conservation areas of MP producers differ ($p < 0.05$) with larger areas in Mato Grosso than in Pará ($p < 0.025$) and in Rondônia ($p < 0.025$) [Table 1 and Figure A3 MP – Appendix].

The relationship between the productive area with low-carbon technology and the total area of the property was lower for AFS adopters (except in Pará), which means that a greater portion of their properties was used for other purposes. These same AFS producers have an average greater proportion of forest conservation area (28%) than MP producers (18%), verified in all states (Table 1).

Livestock farming was the main activity developed on the properties before the implementation of low-carbon technologies. It represented more than 90% of the activity of those producers who implemented MP in Mato Grosso and Rondônia and more than 80% of those who implemented AFS in Mato Grosso and MP in Pará. A part of the producers who implemented AFS in the states of Pará and Rondônia also had agriculture as an activity previously developed in the area. In Pará, AFS producers also had the “other” activity in a representative way (Table 1).

Areas identified as degraded could be corrected by implementing the technology itself. It was noticed that more than half (66%) of the 1,300 producers needed to recover areas within the property. Producers in Mato Grosso have the most degraded areas, followed by producers in Rondônia. Less than half of the producers of each technology in Pará needed to recover the area. With the exception of Pará, the percentages were higher for MP producers, however, the amount of AFS producers identified was also considered high (Table 1).

3.1.1.1 Implanted species

Seven species implanted in MP technologies were mentioned in the state of Mato Grosso and Rondônia and six in the state of Pará, four of the genus *Urochloa* spp. in each state (Table A - Appendix).

In the AFS of Mato Grosso, the most prominent species were *Panicum* spp., *Bertholletia excelsa* Bonpl. and *Eucalyptus* spp. (Table B - Appendix). The main purposes of the different genera and/or species in this state are concentrated on wood, followed by seeds or grains. In the AFS in Pará, *Euterpe* spp. (açaí and others), *Theobroma grandiflorum* (Willd. ex Spreng.) Schum. in Mart. (cupuaçu), *Carapa* *guianensis* Aubl. (andiroba) and *Theobroma cacao* L. (cacao) appeared as a highlight for arboreal fruit trees or for the purpose of seeds production, while *Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster was highlighted in the species for use of pasture by the animal and *Zea mays* L. as an agricultural species. In this state, fruit species are the most prominent, followed by those intended for seeds or grains and later, wood. In Rondônia, AFS presented a greater diversity, but *Tectona grandis* L.f., *Tabebuia* spp. and *Bertholletia excelsa* Bonpl. were highlighted in the arboreal component, *Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster as forage and *Coffea* spp. as an agricultural component (Table B - Appendix). Also, the genera with timber purposes are highlighted in that technology, followed by fruit species and those for seed production.

3.1.2. Socioeconomic characteristics

Men dominated the production systems (76%), mainly in properties that adopt MP (80%) when compared to properties with AFS (69%). Pará is the state where women most appear on properties with MP (30%) and AFS (33%) (Table 2).

Most of the surveyed producers are married (69%) and a portion is single (23%). Pará is the state that most concentrates single producers (38% and 37% for MP and AFS producers, respectively). Rondônia is the only state where singles tend to adopt more AFS than MP. Divorced and widowed mainly adopted AFS.

Most producers do not have formal education (47%). This was observed by 42% of MP producers and 58% of AFS producers. This pattern of lower educational level for AFS producers was maintained in the states, with the exception of Mato Grosso, where these producers appear mainly in the “complete elementary” class. The sum of the interviewed producers who had incomplete and complete higher education represented only 4%.

The average age of producers who implement MP is 50 years old and those who adopt AFS is 48 years old. Many live on the rural property (81%), both MP (80%) and AFS (84%) producers.

Producers who implement AFS have fewer years of experience (25 years) than MP producers (30 years). Respondents in Pará had, on average, fewer years of experience in rural production than in the other states (Table 2).

Table 2. Socioeconomic characteristics of rural producers who implement agroforestry systems (AFS) and managed pasture monoculture (MP) in the states of Mato Grosso, Pará and Rondônia.

Characteristics	Mato Grosso (N = 574)		Pará (N = 420)		Rondônia (N = 306)		Total by technology (N = 1,300)		Total of the study (N = 1,300)
	MP (N = 524)	AFS (N = 50)	MP (N = 244)	AFS (N = 176)	MP (N = 140)	AFS (N = 166)	MP (N =908)	AFS (N =392)	
Producer Gender (%)									
Female	17	32	30	33	16	28	20	31	24
Male	83	68	70	67	84	72	80	69	76
Marital status (%)									
Married	76	68	57	55	78	70	71	63	69
Separate	5	6	2	2	3	5	4	4	4
Not married	16	16	38	37	16	19	22	27	23
Widower	3	10	2	6	3	6	3	7	4
Level of education (%)									
No training	43	28	40	57	40	67	42	58	47
Complete Elementary	34	44	42	16	36	16	37	20	32
Medium Complete	17	24	15	25	17	12	16	20	17
Graduated	6	4	4	2	6	4	5	3	4
Age (years)									
Average $\pm SE$	51 $\pm$ 0.5	49 $\pm$ 2.2	50 $\pm$ 0.9	49 $\pm$ 1.1	49 $\pm$ 1.1	46 $\pm$ 0.93	50 $\pm$0.4	48 $\pm$ 0.7	50 $\pm$ 0.4
Min. e max.	[19–90]	[18–73]	[19–84]	[21–82]	[18–80]	[19–80]	[18–90]	[18–82]	[18–90]
Lives on the property (%)									
No	17	24	23	20	28	9	20	16	19
Yes	83	76	77	80	72	91	80	84	81
Rural production experience (years)									
Average $\pm SE$	30 $\pm$ 0.6	29 $\pm$ 2.3	27 $\pm$ 0.9	22 $\pm$ 1.0	33 $\pm$ 1.2	26 $\pm$ 1.0	30 $\pm$ 0.5	25 $\pm$ 0.7	28 $\pm$ 0.4
Min. e max.	[1–60]	[1–60]	[1–60]	[1–60]	[1–60]	[1–60]	[1–60]	[1–60]	[1–60]
Total workforce (%)									
Familiar	100	100	99	99	99	100	99	100	99
Paid	21	12	23	35	24	17	22	24	23
Family workforce (N)									
Average $\pm SE$	2 $\pm$ 0.0	3 $\pm$ 0.2	3 $\pm$0.1	3 $\pm$ 0.1	2 $\pm$ 0.1	3 $\pm$ 0.1	3 $\pm$ 0.0	3 $\pm$ 0.1	3 $\pm$ 0.0
Min. e max.	[0–6]	[1–5]	[0–6]	[0–9]	[0–9]	[1–8]	[0–9]	[0–9]	[0–9]
Paid workforce (N)									
Average $\pm SE$	0.3 $\pm$ 0.0	0.1 $\pm$ 0.1	0.4 $\pm$ 0.0	0.6 $\pm$ 0.1	0.5 $\pm$ 0.1	0.3 $\pm$ 0.1	0.4 $\pm$ 0.0	0.4 $\pm$ 0.0	0.4 $\pm$ 0.0
Min. e max.	[0–6]	[0–2]	[0–4]	[0–4]	[0–5]	[0–6]	[0–6]	[0–6]	[0–6]
Technical assistance (%)									
No	70	50	71	53	61	36	69	46	62
Yes	30	50	29	47	39	64	31	54	38

(Continue)

(Conclusion)

Characteristics	Mato Grosso (N = 574)		Pará (N = 420)		Rondônia (N = 306)		Total by technology (N = 1,300)		Total of the study (N = 1,300)
	MP (N = 524)	AFS (N = 50)	MP (N = 244)	AFS (N = 176)	MP (N = 140)	AFS (N = 166)	MP (N =908)	AFS (N =392)	
Main economic activity (%)									
Agriculture	0	4	19	69	7	47	6	51	20
Forest	0	0	0	0	0	0	0	0	0
Livestock	97	92	76	27	90	52	90	46	77
Plant extraction	0	2	0	0	0	0	0	0	0
Others	2	2	5	5	3	1	3	3	3
Rural credit (%)									
No	24	40	32	47	14	30	25	39	29
Yes	76	60	68	53	86	70	75	61	71
Family grant (%)									
No	99	90	92	86	96	81	96	85	93
Yes	1	10	8	14	4	19	4	15	7
Retirement (%)									
No	81	64	78	74	79	80	80	75	79
Yes	19	36	22	26	21	20	20	25	21
Rural environmental register - REG (%)									
No	6	8	13	15	11	15	8	14	10
Yes	94	92	87	85	89	85	92	86	90
Affiliation to Rural Producers Union (%)									
No	59	32	32	44	41	49	49	44	48
Yes	41	68	68	56	59	51	51	56	52

AFS: agroforestry system; MP: managed pasture monoculture. “N” means the number of observations performed. “SE” means the standard error of the mean. “Min. and max.” mean the minimum and maximum value, respectively, found.

In all states production is based on family labor, with an average of three people and a maximum of 9. Although few recruits' external workers (23%), in the state of Mato Grosso and Rondônia this recruitment by MP producers prevails, while in Pará, by AFS producers. The average number of workers outside the family is 0.4, with the lowest average for AFS producers in Mato Grosso (Table 2).

Most producers do not receive technical assistance (62%), mainly from MP producers. Most producers who implement AFS are assisted by technical assistance (54%). Pará is the state that concentrates the highest percentage of producers who receive this assistance.

In general, livestock is the main economic activity of MP producers, represented by 90% of respondents. Meanwhile, AFS producers have agriculture and livestock as their main activity, with 51% and 46%, respectively. This pattern is very evident in Pará and Rondônia, however, in the state of Mato Grosso, producers of both technologies have livestock as their main activity.

There is a predominance of producers with access to rural credit (71%). Although the percentage is high for MP (75%) and AFS (61%) producers, the larger pattern is still observed in MP in all states. Rondônia is the state that concentrates more producers with access to credit, while Pará has the least access.

Few producers receive a family allowance (7%) and a pension (21%). The "Bolsa Familia" (financial subsidy from the government for poor families) is more evident by producers who implement AFS, in all states.

Almost all producers have a rural environmental register (90%) and just over half (52%) are affiliated to the rural union of rural producers. There are no major differences for MP and AFS producers.

3.1.3. Management practices depending on the technology implemented

The management practices most developed by producers are the control of undesirable species, soil fertilization, soil correction before planting and rotational management, being more evident by producers in Mato Grosso (Table 3). The use of chemicals and irrigation is less practiced (Table 3).

Almost all producers that introduce MP and AFS technology in Mato Grosso and Pará control undesirable species. In Rondônia, this practice is also widely accepted, but to a lesser extent when compared to other states, especially with MP adopters.

In Mato Grosso, the practice of soil fertilization is more developed by MP producers (95%), while in Pará it is more developed by AFS producers (90%). In Rondônia, this management is almost the same between MP (80%) and AFS (82%) producers (Table 3).

Soil correction before planting is widely developed in Mato Grosso, by AFS (90%) and MP (82%) producers. In Pará and Rondônia, there is a greater variation between producers that adopt the different technologies, being more developed by the producers of MP. Fertilization probably does not come strongly from chemical products, due to poor adhesion. Even so, the most adepts are MP producers in Mato Grosso (41%), followed by MP producers (36%) and AFS (35%) in Pará. Those who least adhere to this use are AFS producers in Mato Grosso (4%) and Rondônia (10%) [Table 3].

Table 3. Management practices carried out in agroforestry systems (AFS) and managed pasture monocultures (MP) in the states of Mato Grosso, Pará and Rondônia.

Characteristics	Mato Grosso (N = 574)		Pará (N = 420)		Rondônia (N = 306)		Total by technology (N = 1,300)		Total of the study (N = 1,300)
	MP (N = 524)	AFS (N = 50)	MP (N = 244)	AFS (N = 176)	MP (N = 140)	AFS (N = 166)	MP (N =908)	AFS (N =392)	
Soil correction (%)									
No	18	10	32	57	23	51	23	48	30
Yes	82	90	68	43	77	49	77	52	70
Use of chemical products (%)									
No	59	96	64	65	74	90	63	80	68
Yes	41	4	36	35	26	10	37	20	32
Irrigation (%)									
No	95	82	96	76	95	80	95	78	90
Yes	5	18	4	24	5	20	5	22	10
Fertilization (%)									
No	5	30	39	10	20	18	17	16	16
Yes	95	70	61	90	80	82	83	84	84
Rotated management (%)									
No	16	30	24	57	49	63	23	56	33
Yes	84	70	76	43	51	37	77	44	67
Control of undesirable species (%)									
No	4	8	7	4	24	15	8	9	8
Yes	96	92	93	96	76	85	92	91	92

“N” means the number of observations performed.

The interviewees from Rondônia are the ones that least develop rotational management. In Pará, the AFS producer (43%) also makes little use of this technique, unlike those who implemented MP (76%). The use of irrigation in the system is almost not used, and those that do are mainly producers with technology with a tree component (AFS).

3.2. Producers' perception of the technologies adopted

Many MP producers in Mato Grosso (75%), almost all in Pará (91%) and half of those in Rondônia (51%) are knowledgeable about low-carbon agriculture. In Pará, a good part of the producers that implement AFS (72%) also report this knowledge. On the other hand, few AFS producers in Mato Grosso (22%) and MP in Rondônia (38%) are aware of low-carbon agriculture (Table 4).

Adopting producers were also asked about the environmental, economic and social impacts after adopting the technologies. Overall, the impacts were positively identified for almost all MP and AFS adopters, with the exception of those interviewed in Rondônia.

Table 4. Perception of producers in relation to technologies implemented in the states of Mato Grosso, Pará and Rondônia.

Characteristics	Mato Grosso (N = 574)		Pará (N = 420)		Rondônia (N = 306)		Total by technology (N = 1,300)		Total of the study (N = 1,300)
	MP (N = 524)	AFS (N = 50)	MP (N = 244)	AFS (N = 176)	MP (N = 140)	AFS (N = 166)	MP (N =908)	AFS (N =392)	
Knowledge about low carbon agriculture (%)									
Know the benefits of low carbon agriculture	75	22	91	72	38	51	73	56	68
Benefits for the producer and property (%)									
Improves family income	91	100	97	99	75	69	90	86	89
Improves productivity	94	100	97	99	83	27	93	67	85
Generates employment	61	18	86	70	55	13	67	38	58
Improves the environmental quality of the property	98	98	72	74	86	51	89	67	82
Creates opportunities for women and youth	55	16	21	43	26	3	41	22	35
Satisfaction with low-carbon technology (%)									
Will continue to adopt technology in the same area	96	100	93	99	87	85	94	93	94
The producer intends to increase the area with the technology	58	82	58	64	49	20	57	47	54
The producer intends to adopt other sustainable technologies	16	18	15	41	4	1	14	20	16
Main contributions to the region (%)									
New productive opportunities	72	100	92	99	58	37	75	72	74
Improved environmental quality in the region	99	98	76	80	76	49	89	68	83
Combating climate change	80	98	17	22	19	2	53	23	44
Contributions from social projects to the region (%)									
Strengthening of local associations or cooperatives	66	22	40	60	6	1	50	29	44
Improvement in the technical level of producers	97	98	56	76	50	2	79	46	69
Improved technical assistance	73	98	7	20	4	1	45	22	38

Almost all MP and AFS producers, mainly in Mato Grosso and Pará, agree that the technology adopted has led to increased income and productivity. In Rondônia, MP producers (75%) perceived these benefits more when compared to AFS producers (69%) [Table 4]. Of the producers who identified the improvement in income, most considered the impact high and medium (Figure 3). In the general average, the AFS producer mainly considers the high impact, while the MP producer considers medium.

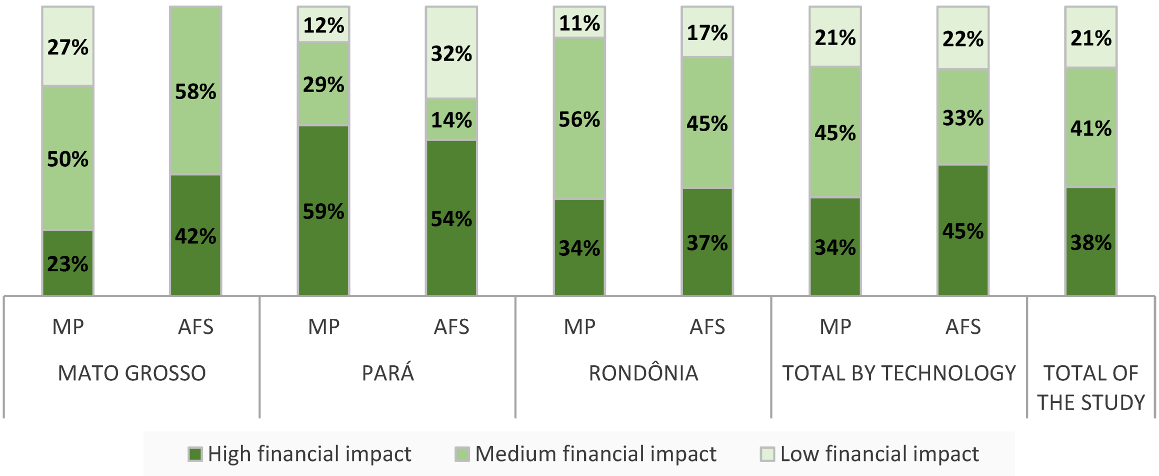

Figure 3. Figure 3. Intensity of impacts generated on the income of producers of agroforestry systems (AFS) and managed pasture monoculture (MP) in the states of Mato Grosso, Pará and Rondônia.

Regarding job creation, those who most agree that there was an increase with the implementation of technology were the producers interviewed in Pará, followed by MP producers in Mato Grosso and Rondônia. Less than 20% of those who implemented AFS in Mato Grosso and Rondônia agreed that there were more jobs after the technology was implemented.

Virtually all respondents from Mato Grosso perceived the improvement in environmental quality (98%). Many producers in Pará and those who adopt MP in Rondônia also agree with this benefit. However, most do not perceive the generation of new opportunities for women and young people, being recognized by just over half of MP producers in Mato Grosso.

Regarding the maintenance of technologies, we found confirmation mainly from AFS producers in Mato Grosso and Pará. With regard to continuing to adopt the technology in the same implanted area, practically all AFS producers in Mato Grosso and Pará agreed. The interviewees from Rondônia were the ones that least affirmed this, but still with high percentages (average of 86%). The interest in increasing the area with the same technology already adopted was agreed mainly by AFS producers in Mato Grosso (82%). Just over half of MP producers in Mato Grosso and AFS and MP producers in Pará also intend to increase the area with the same technology. We did not find the same confirmation from the interviewees from Rondônia. Few producers intend to adopt another low-carbon technology in their area. The most positive responses were from AFS producers in Pará (41%) and the most negative responses were from producers of MP (4%) and AFS (1%) in Rondônia.

When asked to point out the contributions of the implementation of technologies to the region in which they were located, the most positive responses were given by producers in Mato Grosso (mainly AFS), followed by AFS producers in Pará. The lowest approvals were pointed out by interviewees from Rondônia, especially those who adopt the AFS.

Practically all the producers in Pará and the AFS producers in Mato Grosso agree that the implementation of low-carbon technology has opened up new production opportunities for the region. Although almost all producers in Mato Grosso have experienced an improvement in the region's environmental quality and agree that the technology implemented supports the fight against climate change, the same has not been verified in other states. The producers of Pará and those of the MP in Rondônia even agree with the environmental improvement in the region, but in terms of climate change, few affirm this contribution.

Just over half of MP producers in Mato Grosso and AFS in Pará believe that the technology has strengthened local associations or cooperatives. Producers in Rondônia hardly noticed this strengthening.

Practically all the interviewees from Mato Grosso observed a technical improvement of the producers in the region after the social project and, with gaining of knowledge and technical experience about the technologies. Producers in this state, especially those who implement AFS (98%), also noted that there was an improvement in technical assistance. Less expressively, but also relevantly, the producers of Pará and MP in Rondônia also found their technical improvements, although they did not observe the improvement in technical assistance.

4. Discussion

4.1. Characteristics in relation to the technology adopted

We evidenced the almost exclusive participation of small rural producers in the project. The low adherence by the medium may be linked to the fact that larger producers have greater accessibility and ease of investing in production strategies that are environmentally safe [35,61]. This does not mean that these producers are producing sustainably, but they have more resources to do so [62]. In addition, medium-sized producers, who have significant political, social and human capital, may consider the project rules too rigid (for example, conserve a percentage of forests estimated by the project and carry out a certain type of management in the area), which may limit their autonomy in the system [63].

In Mato Grosso, producers basically adopted MP, while in Pará and Rondônia, both MP and AFS were widely accepted. In general, we noticed that MP and AFS producers are similar in some characteristics, for example, the fact that most live on the property, have a low level of knowledge (school level), are mainly married and the workforce is, above all, family, in addition to most developing management of control of undesirable species and fertilization of the system.

However, we tried to look for evidence, even with low representation, that may be directly related to the choice of technology. The data suggest that low-income producers (type P2) and those with smaller areas of property tend to adopt the AFS. On the other hand, larger producers with a greater range of agricultural income are specialized in livestock (MP). This pattern is consistent with the need for producers with better financial conditions to invest their earnings in acquiring more land for the eventual expansion of their herds [64].

On the one hand, there are MP producers with a longer period of rural experience and a greater proportion of area with technology. On the other hand, there are AFS producers (lower income), who work in the rural sector in a relatively shorter time (except for Mato Grosso) and hold a greater proportion of forest conserved area. This could explain the larger area of forest cover and the smaller area cultivated with technology, due to the time of land use on the property. However, with this hypothesis, we would be ignoring that the AFS producer can be more environmentally conscious due to the higher technical level acquired with technical assistance and participation in rural unions, as we have shown. It is evident that participation in local unions and associations can help the producer to express more concerns about the political context [38].

For smallholders to sustain income from livestock production, they need to maximize herd size and thus build economies of scale [64]. This is often done through the opening of new areas and not through intensification, which would justify smaller conservation areas for this group. We know that, with the participation in the SRP I, the producers did not deforest. However, these forest conserved areas portray the situation of the property that already existed.

We have indications that the main economic activity or previous activity developed in the area may have been a determining factor for the adoption of the technology. Our data show that ranchers have a more conservative and risk-averse profile. This is because producers who implemented MP already had livestock as their main economic activity and were already developing livestock in the area where the technology was implemented (Figure 1 and Figure B - Appendix). On the other hand, those producers who have agriculture included in their economic activity are more favorable to changes and are willing to take the risk to implement a new technique such as AFS. In the area where the producers implemented the new technology, there was no pattern of use (livestock, farming and others).

The greater willingness of the farmer to implement a new and diverse technology may be directly related to the tradition of cultivating the species that they already implemented, facilitating management and knowledge. The cultivation of perennial agricultural species (fruit trees) such as cocoa, peach palm and açaí are traditionally implanted in the Amazon biome, mainly by small and medium producers [18]. Some farmers understand that the tree may be necessary in some agricultural crops due to the need for shading for its development [65], being able to provide or receive shade, allowing the cultivation of other tolerant crops [66]. For example, the association of cocoa with forest species such as paricá (*Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby), mahogany (*Swietenia macrophylla* King), ipê-roxo (*Tabebuia heptaphylla* (Vell.) Tol.), laurel (*Cordia alliodora* Cham.), bagassa (*Bagassa guianensis* Aubl.) and Brazil nut (*Bertholletia excelsa* Bonpl.) is a model implemented in approximately 9,000 ha in Rondônia and 140,000 ha in the state of Pará [67]. Cocoa trees (*Theobroma cacao* L.) intercropped with coffee trees (*Coffea canephora* Pierre ex A.Froehner) and teak (*Tectona grandis* L.f.) or andiroba (*Carapa guianensis* Aubl.), are also evidenced in the Amazon by these same authors. Many of these species were evidenced by the producers in our study as implanted in the system (Table B - Appendix).

In general, producers who have adopted low-emission technologies have low educational attainment. However, we show that the greatest knowledge may be concentrated in MP producers (with the exception of Mato Grosso), justified only by the level of education. While greater agricultural knowledge may be associated with the AFS producer, based on the greater technical assistance received.

Even though most of the producers are male, when the woman is present as the head of the rural property, she tends to choose the AFS technology instead of the MP. Studies have demonstrated the importance of women for sustainable development, as they have a greater perception of ecosystem services and seek a more conservationist behavior [68–70]. It is not by chance that gender equality is fundamental to achieving the sustainable development goals (SDGs) for the fulfillment of the 2030 Agenda, an action plan for people, the planet and prosperity, which seeks to strengthen universal peace [71,72].

Not very expressively, but evident in all states, younger age may have been a factor when choosing the AFS technology (Table 2). Younger producers perceive land use and its ecosystem value for food production and provision with greater environmental awareness and valuation [69]. Older producers are more resistant to sustainable innovations in agriculture [73]. Understanding these different perceptions about land use and the environment by age groups of rural producers is an important way to make efficient decisions that dialogue and impact producers in programs for sustainable agricultural development. In Rondônia, some reports show that the transition from a monoculture to an integrated system could be resolved by the succession of farms, where newly trained and university-educated people may be more interested in making the transition to an integrated system [38].

The requirement for paid labor does not define the technology to be adopted, since all producers depend mainly on family strength. However, we know that perennial crops can be more demanding in a given period (planting and harvesting, for example). Not showing this may be linked to the income of the producer, who is unable to pay, which in turn limits the expansion of his economic activities. Thus, the availability of labor can be a crucial factor that limits the economic success of small low-income producers [64].

Producers did not have problems with the REG, as many did not have difficulties in accessing credit, so these are factors independent of technology. However, we noticed that this resource of access to credit was not used for the recovery of degraded areas, since the percentages of producers with this problem were high (less relevant in Pará). Likewise, they were not intended for the implementation of low-carbon technologies, as most realized the benefits generated after adoption with the SRP I, assuming that the techniques were not used.

Amazonian producers still opt for livestock due to the greater liquidity of the activity, however, this production does not seem to be the most profitable for the small producer [74]. Access to credit is often not the problem (as we have also seen), the problem becomes the lack of adaptation as to the purpose and value needed by the producer. It is believed that producers who do not adopt sustainable technologies can be persuaded to do so in the presence of credit [75], since the alternative line of credit is readily available, if not, the producers will not adopt the technology [74]. In Brazil, we have the ABC Program credit line, focused mainly on sustainable development. However, many still consider it bureaucratic and that adjustments, such as the interest rate, should be made in favor of producer demand [76]. In addition to considering broad dissemination among producers and training of bank managers [77,78]. The financial and technical support that the SRP I gave to the producers in our study may have collaborated with other types of systems (such as the AFS) precisely because it is directed and adapted to the local reality of the producer, even if some are reluctant to change.

4.2. Factors related to the choice of technology

We grouped three factors, in random order, that we believe determine the choice of technology in a direct way: (1) regional inclination; (2) tradition (culture); (3) technology transfer. In order to better understand regional suitability and technology transfer, we look at the preliminary information published by the SRP I regarding the Demonstration Units[6] (DUs) contemplated in the project and field days that were held [79]. We have a brief discussion below with this approach.

1- Regional inclination: the local or regional factor where they are inserted probably contributed to the choices. For example, the fact that the Mato Grosso producer mainly adopts MP is justified by the fact that the state is the main beef cattle producer in Brazil [80], with most of its agricultural area dedicated to pastures [7]. MP producers in the states of Pará and Rondônia may also have been driven by local suitability,

[6] The DUs are properties of small or medium producers in which at least one of the technologies supported by the SRP I is already established, being a reference for technology transfer to the producers participating in the Field Days.

which are priority livestock areas [7,81]. This factor can provide the producer with security in relation to the market and regional knowledge, as the production chain is already well structured.

This influence is more evident when we cross-reference our data with the SRP I DUs. In Mato Grosso, 18 MP and 13 AFS DUs were selected. In Pará, 31 DUs were AFS and 10 with MP, while Rondônia had 42 DUs of AFS and 26 of MP. The municipalities that we found with the greatest implementation of MP (Figure 1) had, on average, more demonstrative units of this technique and the same was verified for the AFS technology. For example, in Cotriguaçu, the only municipality in which most producers implemented AFS in the state of Mato Grosso (Figure 1), the six DUs identified were using this technology, while in the other municipalities, the DUs were mainly MP.

This shows us that the AFS is also a relevant system for these regions, even for small and medium-sized producers (as are the SRP I DUs). Thus, we can infer that AFS producers may also have been influenced by relevant activities in the region, which also provides the producer with security in relation to the market and regional knowledge.

Showing the local importance, Skorupa and Manzatto [43] show that 26% of ranchers in Mato Grosso, 39% in Pará and 45% in Rondônia are influenced by neighboring producers and friends to adopt integrated systems, which is considered the main factor in the three states. TV, consulting, field days and others also appear to have an influence, but with less relevance. In Pará, evidence that AFS producers manage the system through information sharing with other producers and observations on the property were also identified in another study [65].

2- Tradition (culture) and knowledge of the producer: we showed, as discussed above, that the rancher (main economic activity) chose to adopt the MP, managing the system in a sustainable way, but not changing the cultivation. On the other hand, farmers seem to be more favorable to the changes, probably because of their knowledge of perennial crops.

According to Cortner et al. [38], in their work developed in Mato Grosso, the lack of personal experience with new technologies can be a determining factor to lead to non-adoption. If knowledge about a particular technology is limited, producers may overestimate the costs and underestimate the benefits [82]. This would be directly related to the need for technology transfer. Furthermore, according to Cortner et al. [38], cultural challenges limit which systems can be installed on farms, where some producers in Mato Grosso report that people do not believe the integration will work or have not seen enough. This lack of knowledge is also reported by Wruck et al. [83], in which producers do not adopt ILPF in Mato Grosso due to problems with technical information and accessibility to start a project with integrated systems.

Producers in Mato Grosso who do not adopt AFS consider that it makes no economic sense, in addition to the difficulty in marketing the final product, while those who implement, diversify the system and include the tree component, are motivated by profitability or by being a more appropriate activity. for certain areas of the property [75]. In addition, many producers point out that the forestry component takes a long time to offer economic return. Also, the stump, coming from the forestry component (when planting wood species), is seen as a barrier to mechanization and as a factor of economic depreciation of the land [83]. Producers who adopt grazing monoculture may simply consider livestock production as simpler, less risky, easier to market and less labor intensive than annual crops [64].

These factors demonstrate the lack of knowledge about a component by those who do not use it. Even because the integrated systems can assume different configurations, being able to be diverse in terms of implementation and maintenance requirements, costs, yields and management [75], it is enough to have models and transference to the producers.

3- Technology transfer: the strengthening of technical knowledge about low-carbon technology may have favored the producer's safety for deciding to adopt a more diversified technology. Some producers in Pará report that in order to adopt systems such as the AFS, it is necessary to disseminate information on the cost-benefits of the system, disseminate information and education, and value the prices of products arising from these systems [65]. In Mato Grosso, Pará and Rondônia, 11%, 58% and 29% of ranchers attribute the lack of information to the non-adoption of integrated systems [43].

The fact that the producer considers that there is little information shows the importance of dissemination through partner projects of public and private institutions, in a way that favors the transition to a more diverse agriculture that benefits the small rural producer. Investments and training of small producers and their families is paramount, as they are important pillars of food supply for local, regional and national society [84,85], and are also important for sustainable rural development.

With this in mind, SRP I took actions to disseminate local knowledge through courses, technology transfer with field days and specialized technical assistance. SRP I trained and made available 91, 135 and 70 technical agents to serve these producers in the states of Mato Grosso, Pará and Rondônia, respectively. It also developed several knowledge materials with a producer orientation [51].

In Mato Grosso, 46 field days were held, with topics on MP (30) and AFS (16). The AFS theme appeared, in total, in 12 days of fields carried out in Cotriguaçu and Nova Canaã do Norte (the only municipalities with AFS in the state). Some municipalities did not have the AFS approach on field days. In Pará, 84 field days were held to disseminate the topic of AFS and seven on the topic of MP. In Rondônia, 92 field days were held, with 74 addressing the topic of AFS and 18 the topic of MP. We found that municipalities with greater implementation of MP (Figure 1) had, on average, more field days directed to this technique and the same was verified for places with AFS prioritization.

Not only the technology transfer of the project may have influenced this, but several knowledge actions that are already carried out in the region. Pereira et al. [86] indicate priority areas for technology transfer actions in AFS, where the regions of our study in the state of Pará and Rondônia are classified as high priority, considered relevant for the adoption process to begin and establish locally or regionally, constituting indicative areas as to the favorability of the adoption process. Areas already considered “favorite” for the adoption of integrated techniques may justify the greater acceptance in our study by the AFS in Pará and Rondônia. The criteria of the study by Pereira et al. [86] were related to the presence of institutional actors, such as the presence of technical assistance and rural extension, cooperatives, unions and faculties; technological profile of the region; and feasibility of access to production outlets, among other criteria. This is also evidenced by Martinez et al. [87], who reports that Pará and Rondônia stand out in the use of AFS due to the consolidation of technological reference units and technology transfer actions, which have been carried out since 2010 and have improved the interest of the producer for the importance of sustainable production processes. The lack of these same factors can justify the low acceptance of the AFS in Mato Grosso, as it is mainly with “very low” or, in some specific municipalities, as “medium” priority.

The focus of the SRP I in the state of Mato Grosso was greater for MP, as well as in some regions of the other states, it may have been a strategy because of the regional inclination, for the adhesion of more producers. The same may have happened with regions that prioritized AFS. However, the dissemination and transfer of knowledge by these projects on intensified technologies, which provide the generation of diverse products, must be prioritized. Mainly because they are small producers in the Amazon, who can generally use smaller areas for agricultural production (20% of the area), depending on the zone of the state. In addition, they are producers of low annual agricultural income, who depend mainly on the income generated on the property (most of them reside on the property). The better use of the land will lead to increased productivity, ensuring the availability of family food, external demands of the region and the production of raw materials, while favoring the environment, social and economic. Producers who implement AFS with perennial crops, as we identified in our study, directly influence the income of small producers. Pacheco [64] in his study in Pará, identified that producers who diversified the intercropping system, perennial crops (fruit trees) and livestock, had higher incomes than those producers with livestock only.

There are studies that indicate that human beings only contribute positively to the environment in situations of awareness of a direct benefit to themselves [88]. Therefore, technologies that increase productivity and family income, generating new productive opportunities and benefits for the environment are guidelines for the challenge of preserving and producing in a sustainable way [75].

In any case, the fact that producers have often left degraded areas for productive ones, shows the importance of local projects in the lives of small low-income producers, regardless of the system adopted. The fact that they still maintain traditional crops such as MP also becomes important, showing that local producers were able to count on external support without losing their autonomous position as artisans and reformers of innovative land use systems [63]. The protagonist and ability to promote new initiatives from the bottom up, with the producer in a central position as agents of sustainable rural development in the Amazon is an important part of this process [63].

4.3. Rural producers' perception of the technology adopted

Studies on perception in the environmental field are relatively new initiatives. The term “perception” includes, in addition to bio-physiological perceptions, the images that are mentally formed about the lived world, memories, experiences, predilections, interpretations, attitudes and expectations [89].

Here we analyze the feasibility of adopting low-carbon technologies from the producer's perspective, considering expectations, satisfactions and dissatisfactions. It has already been suggested in the literature based on field trials that these systems can contribute a variety of social, environmental and economic benefits [19–27]. This information is important, but not sufficient, if this is not identified by the producer. The producer needs to be convinced about the returns that the new techniques are providing, so that he can continue and expand (when possible) the adoption and also spread this information so that more producers are interested. Otherwise, social projects may be temporary solutions.

As previously verified, the influence exerted by neighbors and friends is essential in the process of adopting technologies. This demonstrates the importance of recognizing the benefits of the system for producers to disseminate information. In our study, we evidenced that the perceptions, in general, were positive, especially for the economic aspects by the producers of Mato Grosso, followed by the producers of Pará and Rondônia.

Considering that several producers probably left degraded areas (Table 1), they may have observed these benefits due to the recovery of unproductive areas, improving the productive and economic capacity of the properties, which happens in a short period of time, depending on the species present in the system [90–93]. For technologies such as AFS, production diversification generates increased productivity and economic benefits for producers [13,15]. In addition, many producers already had fruit trees in the system available for harvesting, only enriching them with new components. While MP producers may be related as a result of pasture becoming established and having faster economic returns [94–96].

The social benefit being less evident for AFS producers can be justified by the insertion of fruit trees in the system (Table B - Appendix), in which the harvested products need to be processed immediately after harvesting under exact conditions to obtain the products with high-value that are classified and valued according to their quality standards [66]. This makes the generation of employment intense outside the planting system and is less noticeable by the producer. In addition, due to the labor requirement being concentrated in specific periods of the year (planting and/or harvesting), the social perception is less evident for the producer.

In general, improvements in the environmental quality of the property and region were observed, but the same did not happen with the question related to combating climate change, especially by producers in Rondônia and Pará. This can be explained by the subjective logic of human perception of the climate. For the consolidation of this perception, it is necessary that the producers see the existence of a natural hazard, such as droughts or extreme rains [97,98]. Producers' understanding of climate change is built and shaped from the occurrence of events that indicate these changes and the potential impacts on society [35].

The results indicated that most producers did not perceive improvements in the generation of opportunities for women and young people. It should be noted that the perception of these issues comes from a behavioral change, which is not built in a short period of time [99]. The transformation of the structural patriarchal culture in which society finds itself, based on the exclusion and historical subordination of women, is gradual, pedagogical and generational, and may extend over years[100].

Regarding the maintenance of the technologies after the end of the project, most producers responded that they do not intend to increase their area with the technology or do not intend to implement another type of low-emission technology. This can be explained by the fact that most of the participants are small producers (Table 4), and there may not be more area available for the implementation of other technologies. Despite this, most producers stated that they would continue to adopt the technology in the same area, which demonstrates satisfaction with the benefits and new opportunities generated by them.

Few producers stated that the technologies contributed to the strengthening of associations, local cooperatives and technical assistance in the region, while most noticed improvements in the technical level of the producer. However, studies show that the joint action of cooperativism and technical assistance facilitates the administration and management of technologies, and provides a broader market insertion of production [44,101], even more so in the Amazon, due to its complexity of production chains and the logistical and technological challenges [102]. Thus, actions that contribute to the strengthening of cooperativism and the valorization of adequate technical assistance are important so that interventions and operations carried out by projects or public policies are efficient even after completion and viable in the long term [95,103,104].

It is important to point out that, with the exception of the AFS producer in Rondônia, its technical level has improved. Overcoming technical knowledge deficits through the availability of courses aimed at the agricultural area and technology transfer may have increased the positive perception of producers in relation to low-carbon technology [65].

The benefits of the system being less perceived by Rondônia producers should be considered in other studies. There may have been failures to raise awareness among producers through capacity building and technology transfer. Therefore, the transmission of this knowledge should be improved, as the benefits may not be as visible to the producer in the short term [75,105,106].

In general, in order to understand how one technology is superior to the other in the producer's perception, we would need a control group implementing both technologies. This is because almost all producers left from degraded and less productive areas. That way, any evidence of improvement could be reported.

5. Conclusion

- Agroforestry systems and managed pasture monocultures are key technologies to improve the livelihoods of small rural producers in the Amazon, demonstrated by increasing the income of producers.
- There are great opportunities to improve agricultural and livestock practices in the Amazon with managed pasture monoculture systems and agroforestry systems, demonstrated from improvements in productivity and the environmental properties, with evidence of degraded areas.
- Reconciling agricultural improvements and environmental protection requires greater effort from regional projects focused on the producers' reality, mainly to overcome problems related to tradition, technical knowledge and rural producer income.
- This study highlights the need to consider regional characteristics, socioeconomic conditions and producer perspectives in the development of public policies and programs to encourage sustainable agriculture.

6. Final considerations

Although the focus of producers in the Amazon is monoculture of managed pasture, it is important to keep in mind that agroforestry systems have other important environmental, economic and social advantages when compared to conventional systems. In this context, it would be interesting for research and programs to design small-scale business models that can be used by these small farms with a focus on livestock. Alternative arrangements can help to overcome restrictions in the adoption of agroforestry systems.

Several characteristics that describe the producer (age and gender of the head of the family, education, family and paid workers) did not vary exorbitantly be-tween the producers to differentiate these of the two groups (AFS and MP). This suggests that these characteristics do not need to be considered in isolation in the dissemination of low-carbon technologies. The most important thing would be to consider the factors highlighted, such as age, education and availability of labor, for example, to better develop the approach with producers.

Other particular characteristics of local conditions must be taken into account for the implementation of federal or regional public policies, such as the size of the property, technical knowledge (availability of technical assistance and partnerships with rural unions) and the way producers approach an economy focused on live-stock or agriculture, as they can influence the process of dissemination and acceptance of technologies. Since land use in the Atlantic Forest is strongly influenced by agriculture and livestock, managed pasture monoculture and agroforestry systems can be considered alternatives for sustainable agriculture in this biome as well, however, regional characteristics should be considered in future research. Three main factors can have a direct influence on the technology the producer chooses: regional inclination, producer tradition and technology transfer.

Producers realized that the technologies implemented are economically and environmentally viable activities, and in this way they will continue to use the practice of low carbon emissions. Thus, we infer the importance that local projects can have in changing the system by small, low-income and school-level producers. It is important to highlight that the evaluation of the producer's perception regarding the adoption of technologies and other actions allows public policies and projects to adapt to real local needs, in order to overcome the difficulties encountered by them. We realize that future actions will have to consider in a more incisive way the social benefits of the implantation of technologies and better contributions to the region. We suggest that future projects and actions in this biome are also dedicated to the inclusion of the producer in associations and cooperatives, as they are important factors in the follow-up of sustainable technologies after the completion of local projects.

In general, we show that few studies bring this approach to our study in a broad way. They are usually developed in specific municipalities, limiting regional understanding. The investigation of the potential for dissemination of these technologies is strongly recommended, especially among small producers in the Amazon, whose production systems can contribute, not only to the producer's and family's self-consumption, but also to the mitigation of negative environmental impacts caused by anthropic and environmental action to reduce food and nutrition insecurity in Brazil. We hope that future researches, development plans and local technology transfer programs will focus on the simplest, easiest-to-access, low-cost and flexible improvements in the Amazon, in a way that meets these producers, given the characteristic highlighted. Long-term development plans, based on high cost, labor and a lot of technology may not be suitable for small producers in this region and thus be ineffective.

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Appendix

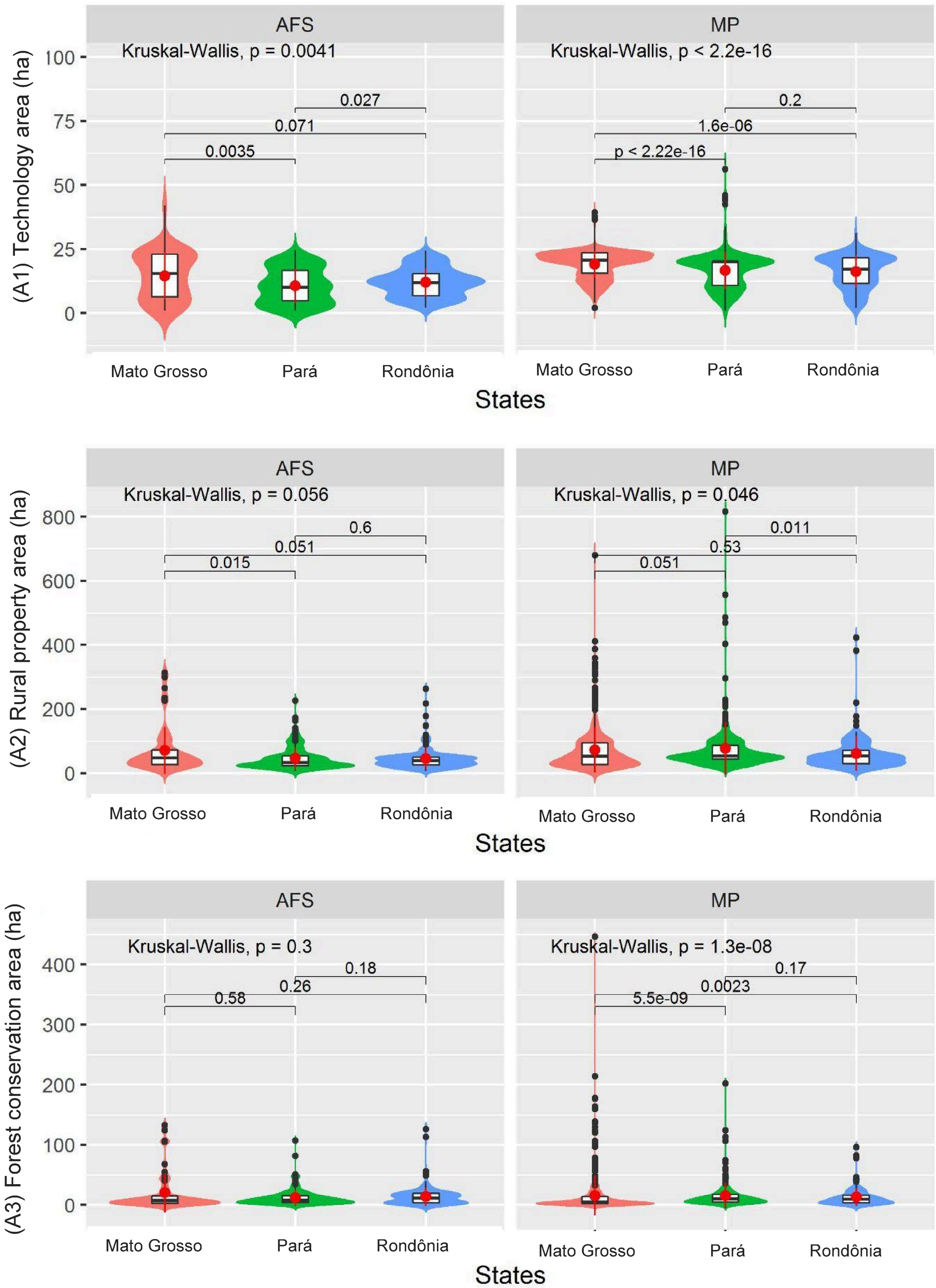

Figure A. Comparison between areas (hectare) of the states of Mato Grosso, Pará and Rondônia for the same technology, as follows: area of implanted technology (A1); rural property area (A2) and; forest conservation areas (A3). Managed Pasture Monoculture (MP) and Agroforestry Systems (AFS). Kruskal-Wallis test $p<0.05$ means that there is a difference between the states. Dunn's test with $p<0.025$ means that there is a difference between the two states evaluated.

Table A. Species and purposes of species observed in managed pasture monoculture (MP) for the states of Mato Grosso, Pará and Rondônia.

Mato Grosso		**Pará**		**Rondônia**	
Species	Number of observations	Species	Number of observations	Species	Number of observa-tions
Panicum spp.	372	*Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster	138	*Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster	76
Urochloa brizantha (Hochst. ex A.Rich.) R.D.Webster	266	*Panicum* spp.	59	*Urochloa* spp.	20
Urochloa humidicola (Rendle) Morrone & Zulo-aga	54	*Urochloa decumbens* (Stapf) R.D.Webster	33	*Panicum* spp.	19
Urochloa spp.	27	*Arachis pintoi* Krapov. & W.C.Greg.	5	*Urochloa humidicola* (Rendle) Morrone & Zuloaga	15
Urochloa decumbens (Stapf) R.D.Webster	13	*Urochloa* spp.	4	*Urochloa decumbens* (Stapf) R.D.Webster	3
Andropogon gayanus Kunth	5	*Urochloa humidicola* (Rendle) Morrone & Zuloaga	3	*Pennisetum* sp.	2
Saccharum officinarum L.	1	-	-	*Cynodon* spp.	1
Grand total	738	Grand total	242	Grand total	136

Table B. Species and purposes of species observed in agroforestry systems (AFS) in the states of Mato Grosso, Pará and Rondônia.

Mato Grosso			**Pará**			**Rondônia**		
Species	Number of observations	Purposes	Species	Number of observations	Purposes	Species	Number of observations	Purposes
Panicum spp.	36	*P*	*Euterpe* spp.	77	*F*	*Tectona grandis* L.f.	85	*W; SC*
Bertholletia excelsa Bonpl.	29	*S/G*	*Panicum* spp.	52	*P*	*Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster	61	*P*
Eucalyptus spp.	14	*W*	*Carapa guianensis* Aubl.	49	*S/G; O; F*	*Coffea* spp.	56	*S/G; F*
Schizolobium spp.	4	*W*	*Theobroma cacao* L.	49	*S/G; F*	*Tabebuia* spp.	56	*W; S/G*
Urochloa humidicola (Ren-dle) Morrone & Zuloaga	3	*P*	*Zea mays* L.	46	*S/G*	*Bertholletia excelsa* Bonpl.	54	*S/G; F; SC*
Coffea spp.	3	*S/G; F*	*Theobroma grandiflorum* (Willd. ex Spreng.) Schum. in Mart.	41	*F; S/G*	*Hymenaea courbaril* L.	37	*W; S/G; F*
Oryza sativa L.	3	*S/G*	*Tabebuia* spp.	29	*W; S/G; SC*	*Schizolobium* spp.	34	*W; S/G*
Tabebuia spp.	3	*W; S/G*	*Eucalyptus* spp.	27	*W*	*Euterpe* spp.	32	*F; S/G*

(Continue)

(Continuation)

Mato Grosso			Pará			Rondônia		
Species	Number of observations	Purposes	Species	Number of observations	Purposes	Species	Number of observations	Purposes
Theobroma cacao L.	3	*S/G*	*Musa* spp.	23	*F*	*Eucalyptus* spp.	30	*W*
Urochloa brizantha (Hochst. ex A.Rich.) R.D.Webster	2	*P*	*Piper nigrum* L.	23	*S/G; F*	*Musa* spp.	30	*F*
Cedrela spp.	2	*W*	*Swietenia macrophylla* King.	20	*S/G; SC*	*Theobroma cacao* L.	29	*S/G; F*
Ceiba speciosa (A.St.-Hil.) Ravenna	2	*W*	*Passiflora* spp.	17	*F*	*Cedrela* spp.	26	*W; S/G*
Musa spp.	2	*F*	*Phaseolus vulgaris* L.	16	*S/G*	*Bixa orellana* L.	22	*S/G; F*
Schizolobium parahyba var. *amazonicum* (Huber ex Ducke) Barneby	2	*W*	*Bertholletia excelsa* Bonpl.	15	*S/G; F*	*Manihot esculenta* Crantz	20	*So*
Inga Mill.	1	*SC*	*Manihot esculenta* Crantz	14	*So*	*Urochloa* spp.	19	*P*
Apuleia leiocarpa (Vogel) J.F.Macbr.	1	*W*	*Khaya* spp.	13	*W*	*Bactris gasipaes* var. *chicha-gui* (H.Karst.) A.J.Hend.	18	*S/G; F; O*
Bixa orellana L.	1	*S/G*	*Anacardium* spp.	11	*F*	*Theobroma grandiflorum* (Willd. ex Spreng.) Schum. in Mart.	17	*F; S/G*
Cajanus cajan (L.) Huth.	1	*S/G*	*Hymenaea courbaril* L.	9	*W*	*Zea mays* L.	13	*S/G*
Cinnamomum spp.	1	*W*	*Cedrela* spp.	7	*W*	*Hevea* spp.	12	*L; SC*
Cordia spp.	1	*W*	*Hevea* spp.	6	*L*	*Urochloa decumbens* (Stapf) R.D.Webster	11	*P*
Crotalaria juncea L.	1	*SC*	*Malpighia* spp.	5	*F*	*Handroanthus* spp.	9	*W*
Khaya spp.	1	*W*	*Bixa orellana* L.	4	*SC; S/G*	*Amburana* spp.	8	*W*
Manihot esculenta Crantz	1	*So*	*Dipteryx odorata* (Aubl.) Forsyth f.	4	*S/G; W*	*Mezilaurus itauba* (Meissn.) Taub. ex Mez	8	*W*
Mezilaurus itauba (Meissn.) Taub. ex Mez	1	*W*	*Spondias mombin* L.	4	*F*	*Copaifera* spp.	7	*O; S/G; L; W*
Phaseolus vulgaris L.	1	*S/G*	*Vouacapoua americana* Aubl.	4	*W*	*Ananas* spp.	6	*F*
Simarouba amara Aubl.	1	*S/G*	*Inga* Mill.	3	*SC*	*Inga* Mill.	5	*SC*
Spondias mombin L.	1	*F*	*Urochloa decumbens* (Stapf) R.D.Webster	3	*P*	*Cucurbita* spp.	5	*F; S/G*
Swietenia macrophylla King.	1	*SC*	*Cucurbita* spp.	3	*S/G*	*Panicum* spp.	5	*P*
Zea mays L.	1	*S/G*	*Selenicereus undatus* (Haw.) D.R. Hunt	3	*F*	*Persea* spp.	5	*S/G; F*

(Continuation)

Mato Grosso			Pará			Rondônia		
Species	Number of observations	Purposes	Species	Number of observations	Purposes	Species	Number of observations	Purposes
-	-		*Pennisetum* sp.	3	*P*	*Phaseolus vulgaris* L.	5	*S/G*
-	-		*Platonia insignis* Mart.	3	*F*	*Anacardium* spp.	4	*F; W*
-	-		*Psidium guajava* L.	3	*F*	*Carapa guianensis* Aubl.	4	*W; O*
-	-		*Azadirachta indica* A. Juss.	2	*W*	*Cordia* spp.	4	*W*
-	-		*Bagassa guianensis* Aubl.	2	*F*	*Crotalaria juncea* L.	4	*SC*
-	-		*Carica papaya* L.	2	*F*	*Ceiba speciosa* (A.St.-Hil.) Ravenna	3	*W; S/G; SC*
-	-		*Citrullus lanatus* (Thunb.) Matsum & Nakai	2	*F*	*Khaya* spp.	3	*W*
-	-		*Citrus* spp.	2	*F*	*Parkia multijuga* Benth.	3	*W*
-	-		*Copaifera* spp.	2	*F; SC*	*Prunus cerasus* L.	3	*W*
-	-		*Vigna unguiculata* (L.) Walp	2	*S/G*	*Swietenia macrophylla* King.	3	*S/G*
-	-		*Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster	1	*P*	*Arachis pintoi* Krapov. & W.C.Greg.	2	*S/G*
-	-		*Urochloa* spp.	1	*P*	*Bagassa guianensis* Aubl.	2	*W*
-	-		*Byrsonima sericea* DC.	1	*F*	*Carica papaya* L.	2	*F*
-	-		*Cordia* spp.	1	*S/G*	*Dinizia excelsa* Ducke.	2	*W*
-	-		*Dalbergia* spp.	1	*SC*	*Dioscorea* spp.	2	*F*
-	-		*Elaeis guineensis* Jacq.	1	*F*	*Peltophorum dubium* (Spreng.) Taub.	2	*W*
-	-		*Eugenia* spp.	1	*SC*	*Protium robustum* (Swart) D. M. Porter	2	*W*
-	-		*Handroanthus* spp.	1	*W*	*Toona ciliata* M. Roem.	2	*W*
-	-		*Schizolobium* spp.	1	*W*	*Annona muricata* L.	1	*F*
-	-		*Simarouba amara* Aubl.	1	*W*	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	1	*W*
-	-		-	-		*Astrocaryum aculeatum* G. Meyer	1	*F*
-	-		-	-		*Attalea speciosa* Mart. ex Spreng.	1	*S/G*
-	-		-	-		*Urochloa humidicola* (Rendle) Morrone & Zuloaga	1	*P*

(Conclusion)

Mato Grosso			Pará			Rondônia		
Species	Number of observations	Purposes	Species	Number of observations	Purposes	Species	Number of observations	Purposes
-	-		-	-		*Cariniana* spp.	1	*SC*
-	-		-	-		*Ceiba speciosa* (A.St.-Hil.) Ravenna	1	*SC*
-	-		-	-		*Cinnamomum* spp.	1	*W*
-	-		-	-		*Citrus* spp.	1	*F*
-	-		-	-		*Cocos nucifera* L.	1	*F*
-	-		-	-		*Colubrina glandulosa* Perkins.	1	*W*
-	-		-	-		*Daphnopsis fasciculata* Meisn. Nevling	1	*W*
-	-		-	-		*Deguelia hatschbachii* A.M.G.Azevedo	1	*W*
-	-		-	-		*Dietes iridioides* (L.) Sweet ex Klatt	1	*W*
-	-		-	-		*Eugenia* spp.	1	*W*
-	-		-	-		*Ipomoea* spp.	1	*So*
-	-		-	-		*Jacaranda* spp.	1	*W*
-	-		-	-		*Neoraputia alba* Nees e Mart. Emmerich ex Kallunki	1	*W*
-	-		-	-		*Paubrasilia echinata* Lam. Gagnon, H.C.Lima & G.P.Le-wis	1	*W*
-	-		-	-		*Piper nigrum* L.	1	*S/G*
-	-		-	-		*Prunus* spp.	1	*W*
-	-		-	-		*Psidium guajava* L.	1	*F*
-	-		-	-		*Pterodon emarginatus* Vogel.	1	*S/G*
-	-		-	-		*Schinus terebinthifolius* Raddi.	1	*W*
-	-		-	-		*Spondias mombin* L.	1	*S/G*
Grand total	123		Grand total	610		Grand total	797	

Information on the "purpose" of the species is exclusive to the producer. Subtitle: Animal pasture (P); Wood (W); Seeds or grains (S/G); Fruit (F); Latex (L); Oil (O); Source (So) and; Shading, soil conservation and/or green manure (SC).

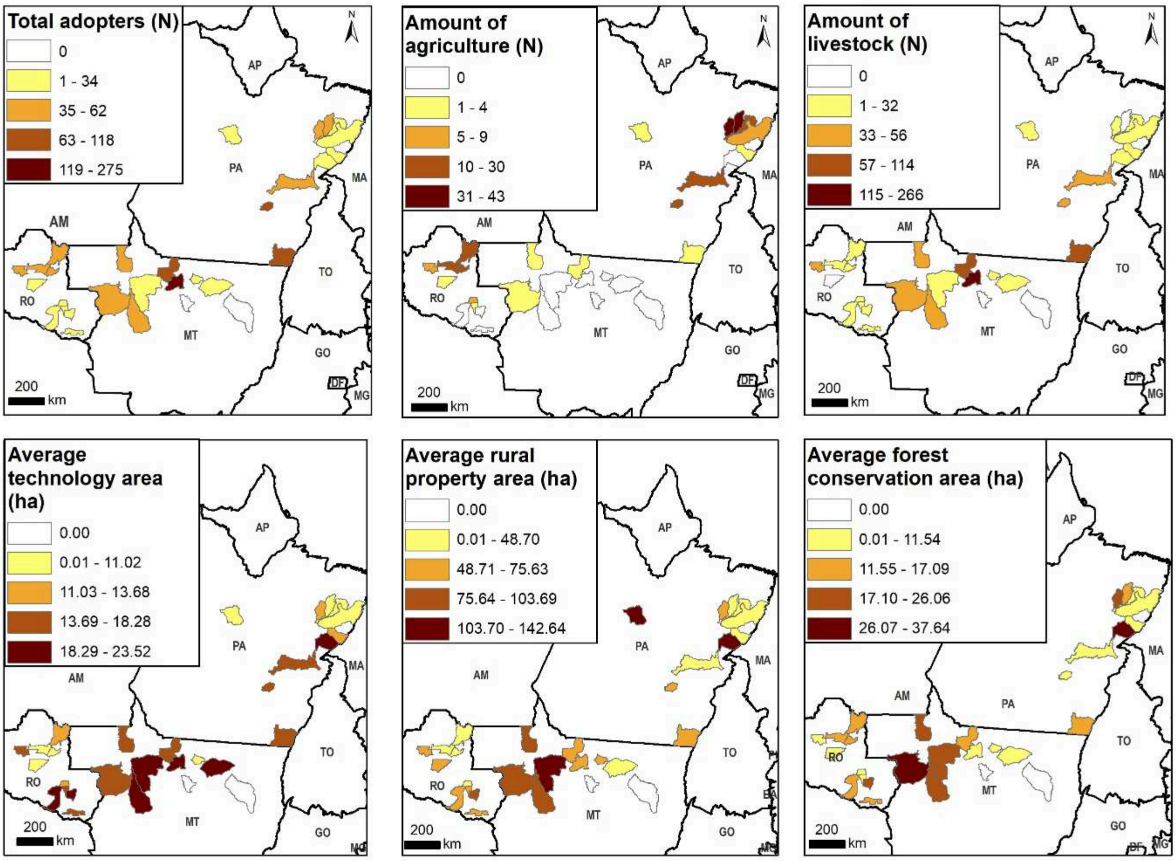

Figure B. Representative maps by municipality: total adopters of low-carbon technologies; amount of agriculture: refers to the number of producers who answered “agriculture” as their main economic activity; amount of livestock: refers to the number of producers who answered “livestock” as their main economic activity; average technology area, average rural property area and average forest conservation area, represented in ranges of hectares. “N” means the number of observations performed.