Challenges and incentives for adopting agroforestry systems: a case study with family farmers in Belterra, Pará, Brazil

Desafios e incentivos à adoção de sistemas agroflorestais: um estudo de caso com agricultores familiares do município de Belterra, Pará, Brasil

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ABSTRACT

The adoption of agroforestry systems (AFS) is challenging for Amazonian family farmers. The objective of this study was to characterise socioeconomic aspects and explore perspectives on the main challenges and incentives highlighted by family farmers involved in the Project of Forest Restoration Through Agroforestry Systems (Prosaf) in Belterra, Pará, Brazil. We conducted a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the project, focusing on 17 family farming properties ranging from 7 to 189 hectares, where agriculture serves as the primary source of income for 71% of participants. The SWOT analysis of the agroforestry systems (AFS) yielded 190 responses: "source of income" was the most frequently mentioned as Strength (18.2%), "cultural practices" and "technical assistance" as Weaknesses (both 18.1%); "infrastructure and resources" as Opportunity (21.4%), and "wildlife predation" as Threat (18.8%). The results demonstrate that AFS in Belterra generate income, improve resilience, and ensure food security but challenges such as insufficient technical assistance and water scarcity highlight the need for support and incentives to maintain this practice.

Keywords: Agrobiodiversity. Prosaf. SWOT Analysis. Silviculture. Food Production.

RESUMO

A adoção de sistemas agroflorestais (SAFs) se mostra um desafio para agricultores familiares amazônicos. Assim, objetivou-se caracterizar aspectos socioeconômicos e compreender as perspectivas sobre os principais desafios e incentivos apontados pelos agricultores envolvidos no Projeto de Restauração Florestal (Prosaf) no município de Belterra, Pará. Foi realizada uma análise utilizando a matriz FOFA (Forças, Oportunidades, Fraquezas e Ameaças), com 17 agricultores familiares. As propriedades variam entre 7 e 189 hectares, sendo a agricultura a principal fonte de renda (71%). Identificaram-se 190 respostas sobre os SAFs: Forças, destacando fonte de renda (18,2%); Oportunidades, com ênfase em "Infraestrutura e recursos" (21,4%); Fraquezas, com destaque para "Tratos culturais" e "Assistência técnica" (ambos com 18,1%); e Ameaça, com "Predação silvestre" (18,8%). Conclui-se que os SAFs em Belterra geram renda, promovem resiliência e segurança alimentar, mas enfrentam desafios, como falta de assistência técnica e escassez hídrica, indicando a necessidade de apoio e fomento para a prática.

Palavras-chave: *Agrobiodiversidade. Prosaf. Análise SWOT. Silvicultura. Produção de alimentos.*

1 INTRODUCTION

Crop-forestry systems are an alternative land-use practice that increases biodiversity, assists in mitigating species loss in natural forests, and contributes to maintaining refuges for native species (Demie *et al*., 2024; Villa *et al*., 2020). This is a production strategy that contributes to food security, while mitigating environmental degradation (Villanueva-González *et al*., 2024; Wilson; Lovell, 2016).

Significant scientific progress has been accomplished in the search for alternative land uses and cultivation practices aligned with environmental conservation principles (Miccolis *et al.*, 2016; Nair, 2011). This emphasises that agroforestry systems (AFS) are sustainable production models, recognised for their diverse and multi-layered composition, with the potential to offer environmental benefits (Mokria *et al.*, 2024; Vasconcellos; Beltrão, 2018). These systems allow for the conservation and rehabilitation of land use in areas with degraded and fragmented forests (Blinn *et al.*, 2013; Villa *et al.*, 2020).

AFS combine species with different functions, promoting interactions in mixed arrangements (Silva, 2014). AFS are recognised for their sustainability, multifunctionality, and high socio-cultural values (Nair *et al.*, 2017), which are important not only for smallholder farmers but for the entire local agricultural community (Nair; Kumar; Nair, 2021). These systems are defined as techniques that intentionally combine forest species with agricultural crops, with or without the presence of animals, in the same land unit (Silva, 2013).

Thus, AFS can be understood as biodiverse agricultural practices for improving food security and cultural identity, as well as increasing well-being in rural properties (González; Kröger, 2020). These production systems are crucial for achieving sustainable development, especially related to food security, sustainable agriculture, and poverty mitigation (Goparaju *et al.*, 2020; Low *et al.*, 2023; Waldron *et al.*, 2017), as well as increasing income in family farms (Arco-Verde; Amaro, 2014; Cardozo *et al.*, 2015; Quandt *et al.*, 2023).

The planting of trees is a trend in these cultivation systems, primarily driven by smallholder farmers, who utilise diverse perennial crops that vary in structural diversity and species richness, presenting heterogeneous production arrangements (Bolfe; Batistella, 2011; Coomes; Burt, 1997; Smith *et al.*, 1996). Thus, the choice of species for intercropping systems is dependent on several factors (Sauvadet *et al.*, 2019; Taillandier *et al.*, 2023). In this context, incentive programs can influence the adoption of AFS (Oliveira *et al.*, 2010) and highlight their multifunctionality, meeting the farmers' objective to adopt these systems (Schaffer *et al.*, 2024).

Motivations and opportunities related to AFS include environmental benefits, food security (Almeida *et al.*, 2023; Oliveira Neto *et al.*, 2022), availability of fruits and medicinal resources, benefits to other crops, and product commercialisation (Lagneaux *et al.*, 2021). Furthermore, AFS are promising strategies for diversifying income by integrating economically valuable trees with food crops and non-timber forest products. This combination increases the economic resilience of smallholder farmers by reducing their dependence on monocultures (Fahad *et al.*, 2022; Mukhlis *et al.*, 2022).

The state of Pará, Brazil, has indirectly encouraged the adoption of AFS in their agriculture public policies, creating the State Plan Amazônia Agora (Pará, 2024) and the State Policy on Climate Change (Legis-PA, 2020). In addition, the Forest Restoration Through Agroforestry Systems Project (Prosaf) of the Pará State Forest and Biodiversity Development Institute (Ideflor-Bio) has promoted the implementation of AFS on small-scale agricultural properties in the state by providing inputs and local partnerships for seedling production, mechanisation, and technical assistance, focusing on the recovery of altered areas as an environmental recovery strategy (Ideflor-Bio, 2024). This project was formalised by Normative Instruction 01/2008, planning to encompass small-scale family farms through the implementation of commercial AFS (Ideflor-Bio, 2018).

The development of knowledge and understanding of land use requires a systemic evaluation, incorporating the experiences of individuals interacting with the environment. Understanding farmers' perceptions of the various factors that guide the adopted AFS and their cultural demands can reveal important aspects for the maintenance, consolidation, and expansion of these production systems. Moreover, the inclusion of the farmers' perspectives in research constitutes an approach focused on those who maintain these crops, encompassing information gaps to produce more inclusive studies.

SWOT (strengths, weaknesses, opportunities, and threats) analysis has been used as a tool for the strategic diagnosis of integrated systems, including AFS, focused on analyzing and collecting information from farmers (Ansolin *et al*., 2020; Jahan *et al*., 2022). SWOT analysis is applied for strategic organisational planning and can be efficiently used to evaluate projects, generating a flow of information (Benzaghta *et al*., 2021; Puyt *et al*., 2023). This tool has been used to identify primary success factors in farming production systems, utilising a participatory methodology strategy (Biassio; Silva, 2015; Borges *et al*., 2024). Thus, it is suitable for assessing the most promoting and limiting factors in AFS, using satisfaction or concern indicators from the perspective of family farmers adopting this practice (Nair *et al*., 2017; Salzmann, 2013).

Despite the Prosaf significance in the context of agroforestry production in Pará, the evaluation of this project is still incipient, especially from the farmers' perspective. Additionally, monitoring and oversight by involved agencies are limited to visits to verify the continuity of plantings and to perform occasional deliveries of inputs and training activities. Specific evaluations of Prosaf have provided information about the profile of farmers involved in the project in the municipality of Mojuí dos Campos (Oliveira *et al*., 2023) and about the collaborative development of AFS arrangements and transitions to new cultivation practices in a settlement in the municipality of Acará (Souza *et al*., 2018). Thus, a deeper understanding of farmers' perceptions of these systems is a crucial factor, as observed in other AFS incentive projects (Alvarado Sandino *et al*., 2023; Fleming *et al*., 2019), that should be addressed together with those involved in AFS in the municipality of Belterra.

Considering the lack of information regarding the development of Prosaf, mainly, the farmers' perspective on AFS, this study focused on identifying internal (strengths and weaknesses) and external (opportunities and threats) factors that may influence the maintenance and continuity of these systems. The inclusion of the social perspective in this information is essential to enable large-scale advances in AFS, denoting its importance for the sustainable development of rural areas in the Brazilian Amazon. Therefore, the objective of this study was to characterise socioeconomic aspects and explore perspectives on the main challenges and incentives highlighted by family farmers involved in the Project of Forest Restoration Through Agroforestry Systems (Prosaf) in Belterra, Pará, Brazil.

2 MATERIAL AND METHODS

The municipality of Belterra, Pará, Brazil, was selected for this study because it has been the most successful location in terms of implementing the Forest Restoration Through Agroforestry Systems Project (Prosaf) in western Pará. Belterra stands out for the establishment of a nursery, distribution of seedlings, and land preparation, according to information provided by staff and technicians from the Pará State Forest and Biodiversity Development Institute (Ideflor-Bio).

An initial sample of 37 family farms from Belterra, registered in Prosaf, was evaluated. However, 17 farms were selected for the research when including only those that remain actively involved in the project, according to the information provided by Ideflor-Bio technicians. The project's activities in the municipality began in 2018, focusing on establishing a plant nursery in collaboration with the Belterra City Hall and assisting farmers in land preparation. The first seedlings were distributed in 2019.

The 17 selected farms were visited and farmers were presented with the objectives of this study and asked for consent to participate in the research. This entire procedure followed the guidelines of the Research Ethics Committee (CEP) of the Federal University of Western Pará (Ufopa). The research was registered and authorised on the Plataforma Brasil under the identification code CAAE 70615423.3.0000.0171.

The study region presents mean temperatures ranging from 25.5 to 26.5 °C, annual mean relative air humidity above 85%, and annual rainfall depths from 2,000 and 2,500 mm, characterised by Am3 and Am4 climate types (Figure 1), according to Xavier *et al*. (2016).

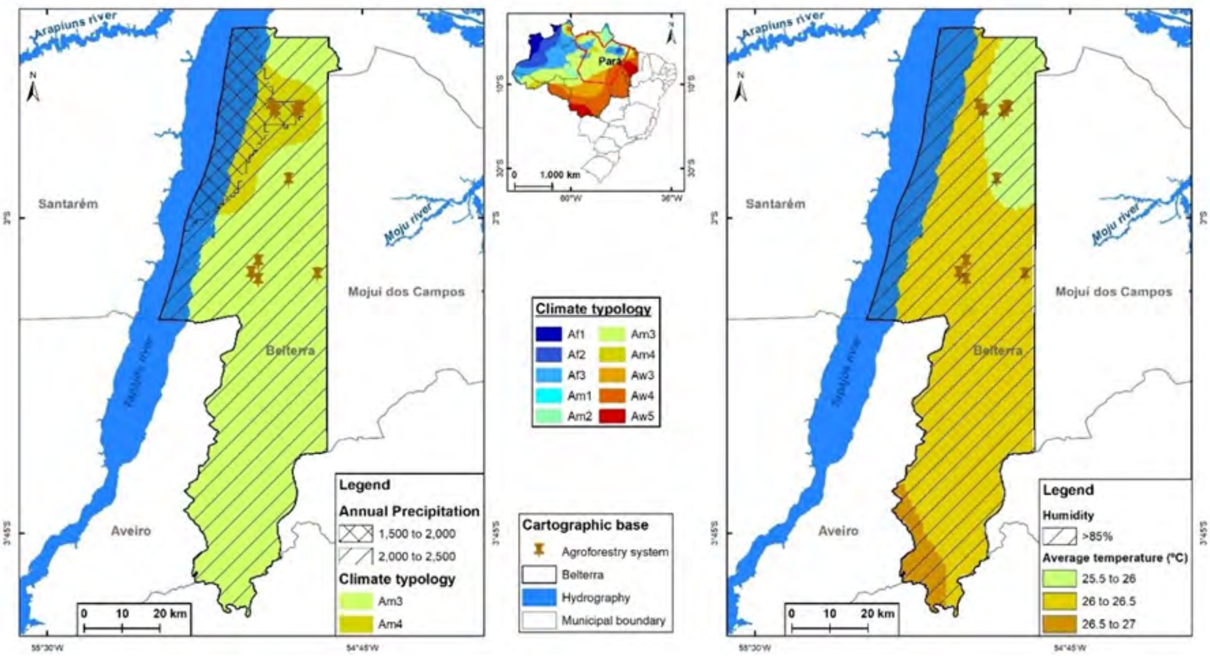

Figure 1 – Rainfall depths, climate type, mean temperatures, and relative air humidity of the study region with family farms involved in the Forest Restoration Through Agroforestry Systems Project (Prosaf), Belterra, Pará, Brazil.

Source: Leila Sheila Silva Lisboa.

Land use classification images from 2020 to 2022 available on the MapBiomas portal (MapBiomas, 2024) enabled the identification of a continuous decrease in forest formation areas in Belterra (from 3,205.73 to 3,162.06 km2), while pasture areas increased, showing 298.10, 318.75, and 332.82 km2 for 2020, 2021, and 2022, respectively. Soybean areas also expanded from 123.8 km2 (2020) to 247.1 km2 (2021), with stability from 2022 onwards (248 km2). Areas cultivated with other short-cycle crops decreased from 2020 (152.7 km2) to 2022 (37.4 km2), denoting a significant dynamic in the cultivation of these crops, probably influenced by price fluctuations and the expansion of crops such as soybean.

The location and different land use categories in 2022 showed that most researched farms are surrounded by pastures and, to a lesser extent, near primary forests and soybean fields (Figure 2).

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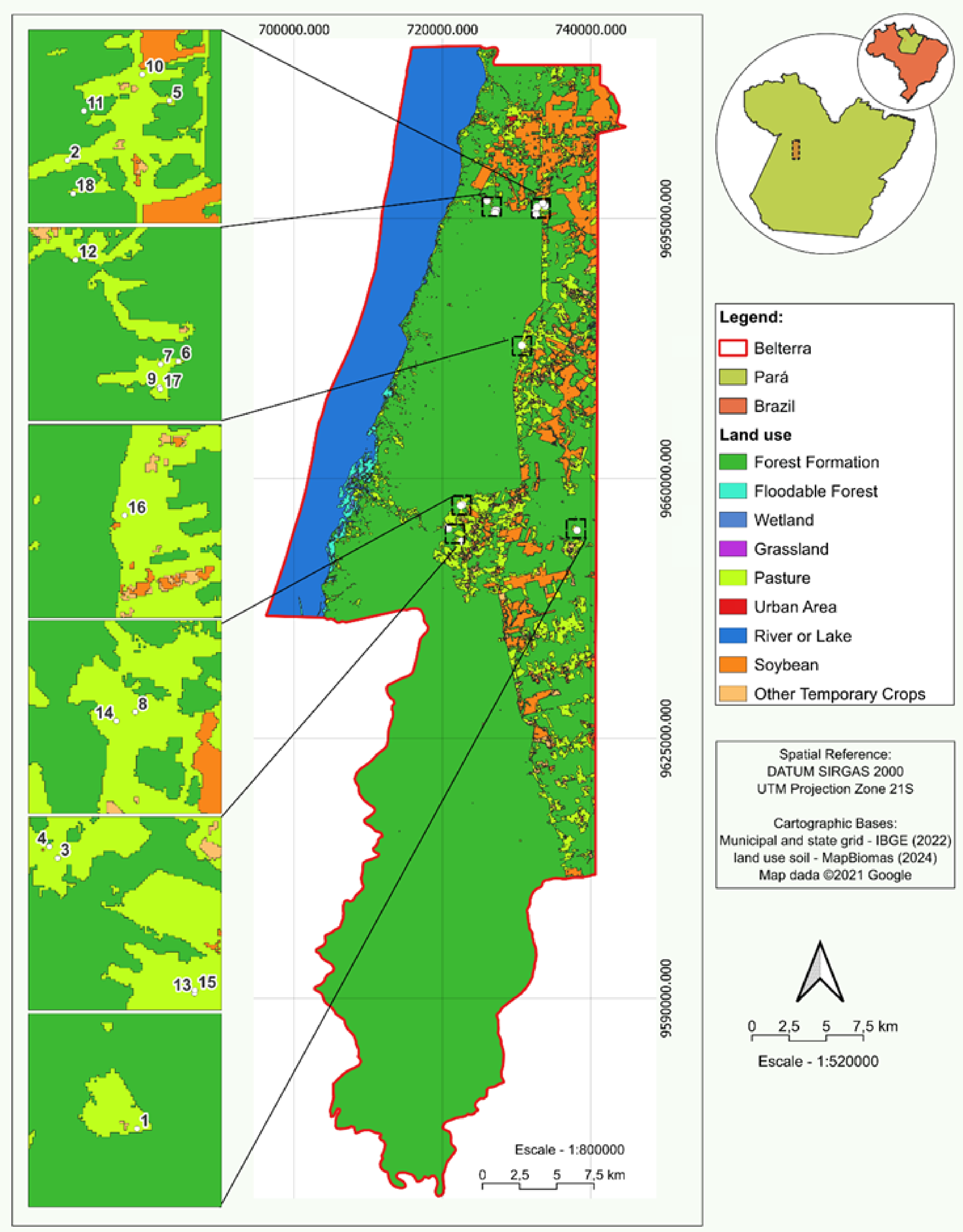

Figure 2 – Land use thematic map of Belterra, Pará, Brazil, highlighting the location of family farms involved in the Forest Restoration Through Agroforestry Systems Project (Prosaf), indicated by numbers 1 to 17. Map created using QGIS 3.34 software based on information from the MapBiomas portal.

Source: Thiago Gomes de Sousa Oliveira

Socioeconomic and production aspects of family farms were assessed through interviews using a semi-structured questionnaire, which addressed the following items: general characteristics of the farm and family, farm size, human resources, sources of income, available infrastructure, associative links, production, occurrence of forest fires, and information on agroforestry systems (AFS). Following the interview, a guided tour was conducted, during which the farmer presented the crops grown and provided additional information about the area.

Another semi-structured questionnaire was applied during the interview and guided tour to conduct a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the AFS (Figure 3). The interview and questionnaire were administered individually to the farmers responsible for the AFS. All procedures were completed within a single day at each farm and were conducted between January and February 2024.

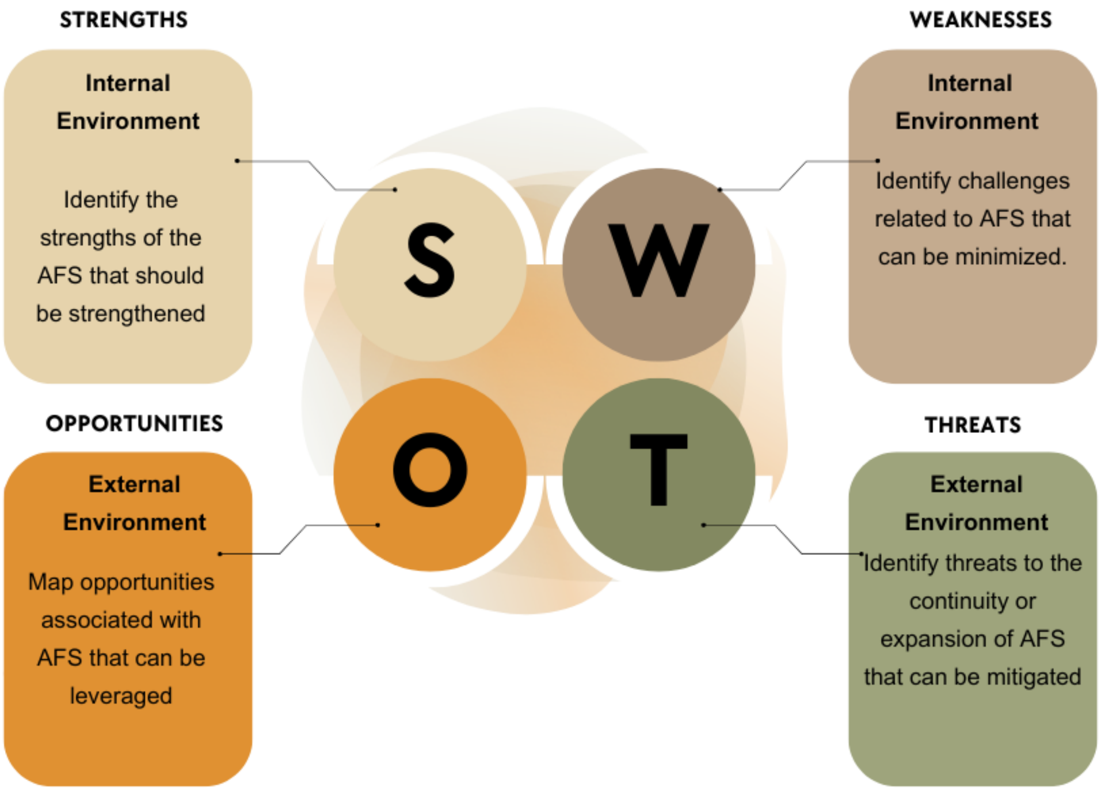

Figure 3 – SWOT analysis diagram of agroforestry systems (AFS) in Belterra, Pará, Brazil, highlighting internal (strengths and weaknesses) and external (opportunities and threats) environmental factors.

Source: The authors.

The responses for each SWOT analysis item were organised and categorised based on content similarity, resulting in a ranking based on response frequency. Categories were established based on the responses, without pre-established definitions. This result allowed for the identification of critical positive and negative points, according to the farmers' perceptions, assessing internal factors (strengths and weaknesses) directly related to agroforestry activities and need to be strengthened or minimised, as well as external factors (opportunities and threats) that extend beyond the agroforestry and the farmer's control but need to be leveraged or addressed.

A stage of this research has not yet been conducted, which involves providing feedback to the farmers involved, both orally and through printed materials, as a form of contribution to them by providing the obtained results. Figure 4 shows the timeline of the main research stages, from the beginning of Prosaf in 2018 to the expected feedback of results to family farmers in 2025.

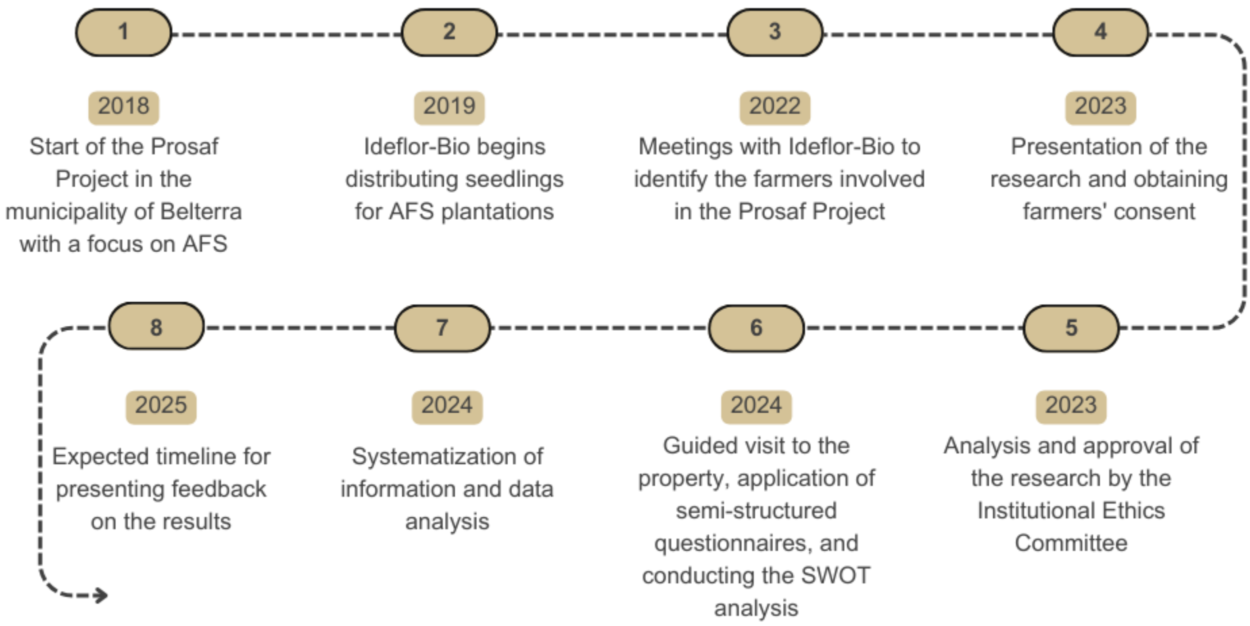

Figure 4 – Timeline of stages of the research on family farms involved in the Forest Restoration Through Agroforestry Systems Project (Prosaf), Belterra, Pará, Brazil.

Source: The authors.

3 RESULTS AND DISCUSSION

3.1 SOCIOECONOMIC ASPECTS

Considering the 17 evaluated family farms, the management of the area is primarily handled by men (94%), while 6% is managed by women. Most farmers were over 40 years old, with a reduced labour force due to the limited number of young people living on the farm. The ages of the farmers ranged from 29 to 66 years, with an average of 53 years for men. Regarding women on these farms, ages ranged from 40 to 61 years, with an average age of 51 years. An analysis of the population involved in the Forest Restoration Through Agroforestry Systems Project (Prosaf) in Mojuí dos Campos, Pará, Brazil, a municipality neighbouring Belterra, showed that most participants were around 45 years old, with income primarily derived from agricultural activities (Oliveira *et al*., 2023).

The families exhibited a large composition, ranging from one to eight children, with the majority (n = 10) having more than three children. Notably, the children of 65% of families no longer live with their parents on the farm, while 35% continue to reside in the family home.

Concerning education, most interviewees have incomplete elementary education (n = 9), indicating a low education level among the farmers. Studies suggest that low educational levels can hinder the adoption of alternative methods and technologies designed to improve crop yields, as well as access to rural credit, essential for investing in agricultural production (Camargo *et al*., 2019; Santos Pompeu *et al*., 2018; Santos; Silva, 2020).

Farm areas ranged from 7 and 189 hectares, with most (59%) falling between 10 to 50 hectares. Most properties (65%) were in rural areas, while 35% were in urban areas, which, in this context, refer to community clusters where health services, schools, and commercial establishments are concentrated.

The number of land-use activities in these areas ranged from one to seven, with an average of three activities. These activities include monocultures, agroforestry systems (AFS), fruit farming, livestock, intercropping, pig farming, and poultry farming. Most interviewees (70.6%) identified agriculture as the primary source of income, while 11.8% reported earning income from external work (manual labour on other properties), 11.8% worked as teachers in the municipal education system, and 5.9% provided services with heavy machinery.

Importantly, 59% of these farmers reported earning additional income from activities such as land leasing, the sale of handicrafts and flowers, passenger transport, sewing, and security services, as well as from Brazilian governmental social assistance programs such as Bolsa Família and retirement earnings.

The number of agricultural and forest products generating income for these properties ranged from 1 to 41, with an average of seven. In this context, 53% of the evaluated properties grew tonka bean (*Dipteryx odorata* Aubl. Forsyth f.) and cassava (mandioca) (*Manihot esculenta Crantz*), the latter grown for flour production; 29% grew cupuaçu (*Theobroma grandiflorum* Willd. ex Spreng); and 24% grew cassava (macaxeira) (*Manihot esculenta Crantz*) and habanero pepper (*Capsicum chinense* Jacq.) and raised chickens. Interestingly, family farmers in Belterra distinguish the *M. esculenta* ethnovarieties mandioca and macaxeira based on production and morphological characteristics, as mandioca roots are primarily processed for flour production, while macaxeira roots are intended for direct consumption (Cunha *et al*., 2016; Pedri *et al*., 2018). These results highlight the importance of growing different species and the production diversity on these farms.

The cultivation of *M. esculenta* for flour production in this region reinforces the economic significance of this crop in the state of Pará, especially in the Lower Amazon region, where this species has historically been the primary crop in family farming properties, making it essential for employment and income generation (Gusmão *et al*., 2016; Santos; Santana, 2012).

The commercialisation of D. *odorata* seeds was mentioned as an important supplementary source of income. This species has a high potential for use in AFS due to its early seed production, high market value, and compatibility with other crops, such as banana (*Musa paradisiaca* L.) and *T. grandiflorum* (Mota *et al*., 2022).

3.2 AGROFORESTRY SYSTEMS MAINTAINED BY FAMILY FARMERS

A total of 48 agroforestry systems (AFS) were mapped among the 17 family farmers, seven of which with only one AFS as a result of the introduction of seedlings from the Prosaf program. Four farmers maintained two AFS arrangements on their properties, two had three, one had four distinct AFS, and only three properties had 6, 8, or 9 AFS. Figure 5 illustrates one of the visited properties in an aerial view (Figure 5a) and one of the mapped AFS (Figure 5b).

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Figure 5 – Orthomosaic image of a rural property in Belterra, Pará, Brazil, generated by drone mapping (a), and an agroforestry system on the farm (b).

Source: The authors.

A total of 68 species were identified among the 48 mapped AFS: 37 fruit-trees or palm species (54.4%); 12 timber species (17.6%); 12 short-cycle or semi-perennial food crop species; 6 species of non-timber forest products; and one species used for natural pest control.

3.3 SWOT ANALYSIS – STRENGTHS AND WEAKNESSES IN AGROFORESTRY SYSTEMS

The SWOT analysis of AFS encompassed 190 responses from family farmers, distributed as follows: Strengths (44 responses), Weaknesses (72), Opportunities (42), and Threats (32). These results evidenced a greater ease of farmers in identifying challenges in AFS, as the Weaknesses category received the highest number of responses.

The responses were grouped and categorised to reflect the farmers' perceptions of the strengths and weaknesses of the AFS implemented on their properties. The analysis addressed the identified advantages and challenges in management and the sustainability of the AFS, providing a comprehensive view of the experiences and expectations of local farmers regarding this cultivation system.

3.3.1 STRENGTHS OF AGROFORESTRY SYSTEMS

"Source of income" was the most frequently mentioned strength by farmers (18.2%) (Table 1), highlighting the economic importance of crops such as passion fruit (*Passiflora edulis*), *M. esculenta*, D. *odorata*, and Barbados cherry (*Malpighia emarginata*). The second most frequently mentioned strength was "Resilience of D. *odorata*" (13.6%), indicating that the species can withstand extreme climate events, such as the *El Niño* phenomenon. "Staggered production" was also significant (11.4%), indicating that the distribution of production throughout the year is an advantage perceived by farmers.

"Production diversification" and "Partnerships" (both with 9.1%) further highlight the importance of diversifying crops, expanding sales options, and establishing local partnerships, such as those with facilities that process *M. esculenta* roots for flour production.

Table 1 – Detailed categories based on responses from family farmers in Belterra, Pará, Brazil, regarding strengths (internal environmental factors), identified through the SWOT analysis of agroforestry systems (AFS) on their properties

Category	*Details*	*Number of responses*	*%*
Source of income	Crops such as passion fruit, *Manihot esculenta*, *Dipteryx odorata*, and acerola were identified as important income sources in the AFS.	8	18.2
Resilience of *Dipteryx odorata*	D. *odorata* was noted for its resilience to the 2023 *El Niño* and water scarcity during the dry season.	6	13.6
Staggered production	Production is available throughout the year.	5	11.4
Production diversification	Increased variety of products through simultaneous crops.	4	9.1
Partnerships	Processing of *M. esculenta* roots in flour production facilities located near the farms.	4	9.1
Environmental conservation	Recognition of the environmental benefits of planting and the advantage of avoiding deforestation to initiate new plantings.	3	6.8
Space optimisation	Intercropping systems allow better use of soil and farm space.	3	6.8
Aesthetic appeal	Satisfaction derived from observing plant growth and the aesthetics of AFS arrangements.	3	6.8
Thermal attenuation	Perennial species provide shade and reduce heat.	2	4.5
Cultural practices	Maintenance is facilitated by increased shade and reduced occurrence of weeds.	2	4.5
Early production	D. *odorata* seed production is precocious, occurring within three to four years.	1	2.3
Fire prevention	Preventive measures have been effective in controlling forest fire occurrences.	1	2.3
Seedling production	Availability of vegetative material for producing their own seedlings.	1	2.3
Autonomous sales	Direct sales channels to consumers.	1	2.3
	TOTAL	**44**	**100**

Source: The authors.

The results indicate that production-related aspects are the primary advantages of AFS cited by farmers. Economic improvement through product diversification beyond the community's primary income source was also identified as a reason for adopting AFS in maroon community (quilombola) territories (Andreata; Mota, 2022). Agroforestry intercropping systems have proven advantageous in reducing costs, increasing income, and improving profitability, especially in terms of non-monetary benefits (Cardozo *et al.*, 2015).

The recognition of production diversification as an advantage in this research aligns with global demands. According to a study on food production, better landscape management combined with a diversified food system can promote global sustainability and support the achievement of the Sustainable Development Goals outlined by the United Nations (Bhagwat, 2022). In multi-species

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systems such as AFS, production diversification is considered an advantage (Jacobi *et al*., 2014) that contributes to increased crop yield and quality (Kieck *et al*., 2016).

Environment-related motivations, reflected by the "environmental conservation", "aesthetic appeal", and "thermal attenuation" were mentioned in 4.5% to 6.8% of responses. Thus, environmental benefits are secondary to production ones for the targeted group in this research, although this perception varies among farmers. Additionally, family farmers in Pará have valued environmental aspects due to historical cultural management practices, the need for shade for certain species, and their recognition of the ecosystem services provided by AFS (Pompeu *et al*., 2017).

Several environmental advantages of AFS have been reported in the literature, including improvements in soil nutrient availability (Muchane *et al*., 2020), organic matter deposition, and soil fertility attributes (Martins *et al*., 2024), benefits of shade trees (Sauvadet *et al*., 2019), and environmental and ecosystem services provided by tree-dense environments (Almeida *et al*., 2023; Jadán *et al*., 2015). These benefits also include the shading for perennial crops, which mitigates water deficits and improves the local climate.

3.3.2 WEAKNESSES OF AGROFORESTRY SYSTEMS

The primary mentioned weaknesses of AFS were "cultural practices" and "technical assistance", each accounting for 18.1% of responses (Table 2). The two major challenges highlighted were the high demand for management practices such as pruning and disease control and the lack of proper technical support to manage diverse plant species. The third most frequently mentioned factor was "water access" (13.9%), denoting the scarcity of water resources, especially for irrigation, due to the collective use of artesian wells, which hinders water use for irrigating both agricultural and forest plantations. Other significant weaknesses include "losses" (6.9%), mainly due to seedling mortality during adverse climate events such as *El Niño*, and the lack of "mechanised support" (5.6%), indicating the need for more appropriate equipment to increase management efficiency in AFS

Table 2 – Detailed categories based on responses from family farmers in Belterra, Pará, Brazil, regarding weaknesses (internal environmental factors) identified through the SWOT analysis of agroforestry systems (AFS) on their properties.

Category	*Details*	*Number of responses*	*%*
Cultural practices	Increased demand for activities such as pruning (cacao trees), disease control, weed (Santalacea sp.) removal from trees, cleaning, and herbicide application for weed control, as well as the need to replant passion fruit crops every two years.	13	18.1
Technical assistance	Insufficient technical support for managing several crops, identifying diseases, and providing guidance on the application of inputs and fertilizers.	13	18.1
Water access	Limited access to water for irrigation due to the collective use of artesian wells.	10	13.9
Losses	Lack of interest in replanting cacao, *Theobroma grandiflorum*, and Aniba rosaeodora Ducke seedlings due to high mortality during *El Niño* periods.	5	6.9
Mechanised support	Outdated and inadequate equipment for efficiently managing AFS.	4	5.6
Climate vulnerability	Low yield of *T. grandiflorum*, Bactris gasipaes, and avocado during droughts, as evidenced during the 2023 *El Niño* phenomenon.	4	5.6
Seedlings	Inefficient seedling delivery by support agencies, mainly cacao seedlings, or lack of high-quality black pepper seedlings.	4	5.6

Category	Details	Number of responses	%
Resources	Limited investments in AFS due to banking system debt or lack of financial support from government agencies.	4	5.6
Soil fertilisation	Need for access to proper soil fertilisation tailored to each crop, based on soil analysis.	3	4.2
Animal predation	Predation of *Dipteryx odorata* and B. gasipaes fruits by bats and birds, respectively.	3	4.2
Electricity	Lack of or insufficient electricity for installing irrigation pumps.	3	4.2
Limited knowledge	Need for training and guidance on pruning and on newly introduced species.	2	2.8
Production	Shading reduces the yield of intercropped species that require greater light exposure.	2	2.8
Discontinuity of planting	Lack of interest in continuing the planting of forest species such as D. *odorata*.	1	1.4
Forest fires	Firebreaks were ineffective in preventing forest fires.	1	1.4
	TOTAL	**72**	**100**

Source: The authors.

These weaknesses included concerns about the selection of plants for pruning. Pruning in cacao and *T. grandiflorum* plantations are performed to achieve higher fruit production. Pruning in D. *odorata* plantations is performed to create space under the canopy to facilitate fruit harvesting, thus, it is more of an operational measure than a management practice to increase fruit production. Similarly, Torquebiau (2000) reported that trees and agricultural crops within AFS grow under competition for natural resources, and the management and allocation of resources, such as labour, must also be shared.

Irrigation was used in only 18% of the properties, while 82% had no irrigation systems. This is primarily attributed to the water sources available in these properties, as most of them (59%) depend on shared artesian wells or streams. Additionally, the absence of electricity in some properties (n = 3) contributes to the lack of irrigation. Most properties with electricity are connected to the public energy grid (n = 11), while two use solar power and one relies on a generator.

The lack of an irrigation system was identified as a significant limiting factor for the continuity of crops, mainly those with lower resistance to water deficits. This factor was emphasised by farmers, frequently mentioning the 2023 *El Niño* event during the interviews conducted in February 2024. This event caused significant losses, especially in *T. grandiflorum* and cacao plantations, and reduced banana production. Additionally, the risk of forest fires was also mentioned as a weakness (1.4%).

Limitations in agricultural extension services and insufficient knowledge about AFS are obstacles to the adoption of crop-forestry systems (Sills; Caviglia-Harris, 2015). Studies in Pará reported that the official agency for technical assistance has provided support to AFS only during the initial years of establishment, which led to implementation failures, emphasising that managerial support provides farmers with greater confidence in the establishment and management of these systems (Pompeu *et al*., 2017; Pompeu *et al*., 2012).

Similarly, the lack of inputs and technology to improve the systems was frequently reported as a weakness in a SWOT analysis of several AFS worldwide (Nair *et al*., 2017), indicating that different contexts in agroforestry systems share structural similarities.

3.3.3 Opportunities for agroforestry systems

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Positive external environmental factors (Opportunities) included "Infrastructure and resources" (21.4%) as the most frequently identified opportunity of AFS (Table 3). This highlights the expectation that adopting this system would assist in improving infrastructure, including access to electricity and implementation of processing facilities, as well as the availability of resources for inputs and equipment. "Irrigation" was the second most frequently mentioned factor (19%), reflecting the expectation or need for installing irrigation systems to increase production and diversify crops. "Expansion of plantings" (11.9%) and "diversification of plantings" (9.5%) were also significant, indicating a growing interest in expanding perennial crops and incorporating timber species into the system, which suggests that permanent planting has a catalyzing effect. Finally, "associations and partnerships" (7.1%) was identified as an opportunity to strengthen marketing through group organisation and collaboration.

Table 3 – Detailed categories based on responses from family farmers in Belterra, Pará, Brazil, regarding opportunities (external environmental factors) identified through the SWOT analysis of agroforestry systems (AFS) on their properties.

Category	*Details*	*Number of responses*	*%*
Infrastructure and resources	Improvement of processing infrastructure, electricity distribution, waste utilisation, and availability of resources for acquiring inputs and planting equipment.	9	21.4
Irrigation	Installation of irrigation systems to increase production and diversify crops.	8	19.0
Expansion of plantings	Interest in expanding perennial crops.	5	11.9
Diversification of plantings	Diversification of plantations by including timber species.	4	9.5
Associations and partnerships	Joining or organising groups to strengthen product commercialisation.	3	7.1
Inputs	Expectation of receiving planting inputs from governmental and development institutions.	3	7.1
Environmental services	Recognition for the environmental benefits generated by plantations.	3	7.1
Family future	Expectation of maintaining plantations to ensure benefits for future generations.	2	4.8
Introduction of animal components	Installation of infrastructure to integrate animals into the AFS.	2	4.8
High-quality materials	Access to resistant genetic material to replace diseased plants.	1	2.4
Green barriers	Planting tree species such as Khaya sp. and Tabebuia sp. as a windbreak barrier.	1	2.4
Seeds	The possibility of exchanging AFS seeds for seedlings.	1	2.4
	TOTAL	**42**	**100**

Source: The authors.

The mentioned opportunities perceived by some farmers included the recognition of AFS as a strategy for leaving a family legacy through the continued planting of perennial species. In addition, some farmers consider these small-scale plantations as investments for the future, with benefits for subsequent generations (Thomas; Van Damme, 2010), consolidating these plantings as a heritage for descendants (Andreata; Mota, 2022). Experiences in Tomé-Açu, Pará, suggest that these systems compose a socio-technological complex, offering a path to sustainable agricultural development in the Amazon (Futemma *et al*., 2020).

Environmental services provided by AFS were mentioned by 7.1% of farmers, while the benefits of green barriers and the possibility of exchanging seeds for seedlings were mentioned by 2.4%. These responses indicate an expectation of environmental valuation and investment in these systems. Despite these expectations, adequate policies and investments in AFS should be prioritised (Goparaju *et al.*, 2020), including for scientific research, as well as institutional and policy changes (Nair *et al.*, 2021).

3.3.4 THREATS TO AGROFORESTRY SYSTEMS

Regarding negative external environmental factors (Threats), "wildlife predation" was the most frequently mentioned (18.8%) (Table 4), referring to damages caused by animals, including bats and agoutis, that affect fruit and seedling production. The second most frequently mentioned factor was "information scarcity" (15.6%), referring to the lack of technical knowledge in managing mixed crop species and dealing with unknown diseases, such as those affecting cacao plantations. "Family conflicts" (9.4%) and "forest fires" (9.4%) are social and environmental factors that also may hinder the continuity and safety of these planting systems. "Demotivation" (9.4%) completes the group of the most significant threats recognised by farmers, indicating the risk of discontinuing the activities.

Table 4 – Detailed categories based on responses from family farmers in Belterra, Pará, Brazil, regarding threats (external environmental factors) identified through the SWOT analysis of agroforestry systems (AFS) on their properties.

Category	*Details*	*Number of responses*	*%*
Wildlife predation	Damage caused by wildlife predation, such as bats and agoutis, resulting in the loss of fruits and seedlings of *Dipteryx odorata* and Bertholletia excelsa (Brazil nuts).	6	18.8
Information scarcity	New experience with intercropping and crops for which knowledge on management (e.g., cacao) and potential diseases is still lacking.	5	15.6
Family conflicts	Influence of family problems, inheritance, and divorce that may interfere with the continuity of agricultural activities.	3	9.4
Forest fires	Risk of fires originating from neighbouring properties, increased by the absence or ineffectiveness of firebreaks to control the spread of fire.	3	9.4
Demotivation	Lack of interest in the area, leading to abandonment and cessation of cultural practices in plantations.	3	9.4
Production uncertainty	Need to maintain homogeneous areas with short-cycle crops (open fields) to ensure production security.	2	6.3
Production theft	Individuals illegally entering the property to collect Brazil nuts and harvest *Manihot esculenta*.	2	6.3
Pesticide use	Application of pesticides on neighbouring properties due to extensive agriculture practices.	2	6.3
Drought impact	Loss of seedlings and delayed effects of *El Niño* on production, requiring a long recovery period for crops.	2	6.3
Cross impact	In intercropping systems, the harvest of one crop can compromise or damage another species.	1	3.1
Product price	Concern over the potential devaluation of D. *odorata* seeds.	1	3.1
Land sale	Land speculation by agribusiness producers in land acquisition.	1	3.1
Environmental contradiction	Inconsistency between environmental preservation discourse and limited support action.	1	3.1
TOTAL		**32**	**100**

Source: The authors.

Animal predation was mentioned as a weakness in AFS (Table 2), but with less significance compared to its recognition as the most relevant threat to the systems (Table 4). This factor is related to the predation of immature fruits by bats that feed on the endocarp, potentially causing losses of up to 30%, according to the interviewed farmers.

Forest fires were mentioned by 65% of farmers, who reported their occurrence on their properties, mainly during 2023 due to the *El Niño* phenomenon. Although some farmers use firebreaks, this measure is often ineffective. However, despite the high occurrence of fires, these events were not considered significant either as a threat or a weakness in AFS.

During research activities, several farmers were growing short-cycle crops, such as *M. esculenta*, maize, and common beans, in homogeneous systems. These farmers plant these crops and carry out cleaning and pruning in AFS areas, indicating that AFS activities are a secondary priority in their farm routine. This scenario is connected to "production uncertainty" (6.3%), which reflects the need to maintain monocultures as a primary activity due to the farmers' established knowledge of these crops, ensuring production security. Similar weaknesses and threats to the adoption and continuity of AFS in the Amazon have been reported in the literature (Hoch *et al*., 2009; Iverson; Iverson, 2021; Jacobi *et al*., 2014; Lagneaux *et al*., 2021), highlighting the concerns and challenges shared by farmers in Belterra, such as access to quality seeds and seedlings, operational difficulties in mixed systems, and insufficient information on specific agricultural practices.

These common threats and challenges show that relevant institutions and organisations should increase their support to farmers committed to perennial crops, despite the limitations outlined in this study. Most farmers recognise the importance of providing economic incentives, particularly for tree planting (Robiglio; Reyes, 2016) to avoid future reports of failure with AFS in Belterra, as seen in other Amazonian regions (Hoch *et al*., 2009; Sills; Caviglia-Harris, 2015).

A limitation of this study was the exclusion of family farmers who did not continue their participation in the Prosaf Project, which could have revealed important aspects regarding the challenges and potential of AFS. Moreover, the study was conducted with participants of the Prosaf Project in Belterra, and other evaluations of the project in different regions may yield different results.

Therefore, future studies addressing farmers’ perspectives on the adoption and maintenance of ASF should include other target groups who also adopt AFS but have different sources of incentives and funding. This approach would allow for obtaining diverse opinions on these challenges. Additionally, farmers should be continuously monitored, considering different climatic events, as well as commercial and production variations, focusing on capturing different situations.

4 CONCLUSIONS

The agroforestry systems (AFS) implemented in Belterra, Pará, Brazil, through the Forest Restoration Through Agroforestry Systems Project (Prosaf) of the Pará State Forest and Biodiversity Development Institute (Ideflor-Bio) showed to be a viable alternative for diversifying production for family farmers, highlighting the importance of agricultural activity, particularly in terms of food production. The main identified strengths include income generation, indicating that these systems can be an effective strategy for economic sustainability and resilience to climate events. Seasonal production distribution, crop diversification, and strengthening of local partnerships evidenced the potential of AFS to contribute to food security.

However, family farmers involved in Prosaf in Belterra reported challenges for the adoption and continuity of AFS, including the demand for cultural practices and the lack of adequate technical assistance, emphasising the need for support to ensure efficient AFS management. Water scarcity and vulnerability to climate change were also presented as additional difficulties that threaten the sustainability of these systems.

The listing of critical points of AFS mentioned by farmers may serve as a foundation for decision-making and for defining strategies for the continuity and expansion of these production systems, promoting social, financial, and environmental sustainability. This mapping is an analytical tool for guiding development projects, enabling the creation of intersectoral action plans involving funding institutions, technical assistants, educational institutions, and farmers to devise multifaceted strategies and improve effective actions in intercropped systems.

Based on the SWOT analysis results, the main positive aspects (strengths and opportunities) should be strengthened and leveraged for the success of AFS implemented through Prosaf and those initiated by farmers themselves. These positive aspects include the expansion of perennial plantings, cultivation of tonka bean (*Dipteryx odorata*), expectation of investments, production diversification, and income generation. These incentives can also include recognising agroforestry cultivation as a strategy for environmental conservation.

External support focused on addressing issues related to cultural practices, input demands, technical assistance, and irrigation system installation is required for overcoming or mitigating the identified negative aspects (threats and weaknesses). Additionally, investments in training on the specific requirements of the cultivated species and on strategies to reduce production losses are essential for maintaining and expanding AFS on family farms.

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