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RESEARCH

Farm Knowledge Co-Production at an Old Amazonian Frontier: Case of the Agroforestry System in Tomé-Açu, Brazil

Fabio de Castro* and Celia Futemma†

This paper addresses how co-producing knowledge can assist local farmers in reshaping their territories into sustainable farming systems. We describe the emergence and consolidation of an agroforestry system in an Eastern Amazon forest frontier, unpacking the co-production of a new farming system over recent decades. Instead of assuming pre-defined categories (e.g., traditional/technical, local/external), the analysis focuses on interactions among knowledge holders and how multiple knowledge sources are intercalated. The analysis is based on long-term ethnographic research, comprising of over 70 interviews, visits to 40 farm fields, and participation in several local meetings and four annual seminars. The agroforestry system – locally called SAFTA – has emerged from a farming crisis experienced by mid-scale farmers of Japanese descent. Grounded in traditional Amazonian farming practices, SAFTA has been enriched by scientific and organizational knowledge from various sources to become a local solution that reconciles economic, social and environmental demands. Built on a few basic principles, this new farm system enables flexibility in crop field designs according to each farmer's preferences and available resources. SAFTA knowledge has spilled over to other farmer groups and has helped develop an innovative agroforestry system for oil-palm cultivation. The SAFTA model has been consolidated, legitimized by a range of national and international actors, and gradually institutionalized in policy and commercial circles. This case sheds light on the potential of knowledge co-production to transform complex rural landscapes featuring cultural diversity, asymmetrical relationships and history of land-use change. Analysis of social interactions and knowledge integration mechanisms give insight into how co-production under local cultural diversity and asymmetrical relations may yield mutual benefits among local farmer groups.

Keywords: Knowledge co-production; Amazon; Agroforestry Systems; Forest Frontier; Rural Landscape Transformation

1. Introduction

Farm knowledge building and exchange are fundamental elements in rural development. In Latin America, several studies attest to local farmers' transformative power in co-producing sustainable, inclusive farming systems with researchers (e.g., Holt-Gimenez, 2006; Altieri and Toledo, 2011). These authors emphasize the importance of farmers' knowledge and their leading role in this process. In this article, we discuss local farmers' role in leading farm knowledge co-production at an old forest frontier. Forest frontiers are spaces reshaping the rural landscape with complex dynamics. Access to land and resources attracts new actors, such as an array of migrant farmers and extractive industries, to the region. They bring new technologies, knowledge, and norms, leading to multiple interactions, practices and institutional arrangements (Rassmussen and Lund, 2018). Academic debates on forest frontiers center on how policies, market pressures, violence, and illicit practices drive social and ecological impacts, such as deforestation, land dispossession, migration, and conflicts (see, e.g., Ioris, Ioris and Shubin, 2020). Less attention is given to how new encounters among multiple knowledge sources may promote mutual learning and inspire innovation. Without losing sight of the intensity and speed of the above socioenvironmental impacts, this paper focuses on how local actors can foster farm knowledge co-production and reshape their territories into sustainable production systems at forest frontiers.

Knowledge co-production is a polysemic concept in rural development and sustainability literature (Norström et al., 2020). It is often associated with transdisciplinary research by researchers with local stakeholders (Djenontin and Meadow, 2018), normative perspectives of social inclusion (Campbell, Svendsen and Roman, 2016), and more broadly to blending of multiple knowledge sources (Lemos and Morehouse, 2005). Emphasis on knowledge encounters

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and inclusiveness, however, masks power issues in this process. Agrawal (1995) argues that assuming differences in methods, epistemology, and contextuality between scientific and non-scientific knowledge sources not only reinforces pre-established hierarchies in legitimacy and applicability but also overlooks commonalities across knowledge categories or their internal diversity. Turnhout et al. (2020) address the need for more attention to the dark side of knowledge co-production, when power asymmetries and hierarchies among 'co-producers' are enhanced rather than mitigated. This paper addresses these critical perspectives by addressing knowledge co-production in practice between farmers occupying different social positions, and a range of outside actors. However, instead of holding any assumption about this context, we provide a nuanced analysis of how different knowledge sources are integrated into a heterogeneous social context. We analyze the emergence and consolidation of a new agroforestry system by focusing on interactions among knowledge holders and mechanisms of interaction among different knowledge sources.

Agroforestry systems (AFSs) are economic production systems based on practices that mimic forest structure in order to improve multiple synergistic effects (van Noordwijk, 2019). These locally based land-use practices combine aspects of agriculture and forestry, which provide sustainable production through ecologically and economically efficient production (Nair and Garrity, 2011). AFSs are spread worldwide and span a broad range of models, from fluid multi-crop systems to highly structured arrangements of crop species consortia (FAO, 2019). In common, they are grounded in ongoing experimentation with tree-crop cultivation techniques inspired by forest-based structures and functions (van Noordwijk, 2019).

In the Brazilian Amazon, AFSs have been regarded by large-scale farmers and governmental authorities as a remnant of primitive production systems, to be replaced by more efficient land-use systems. This perspective started to change in the 1990s, when the growing literature on agroforestry revealed these systems' diversity and relevance to supporting sustainable production systems' design (Barton, 1994; Porro, 2012). Despite their increased visibility, AFSs still carry an idealized image in policy circles as extensive production systems practiced by traditional populations and mainly geared to supporting local economies. As a result, agroforestry is usually associated with scattered initiatives to potentially support forest conservation and local food security. Agroforestry systems in the Amazon, however, comprise a broader range of production systems and economic arrangements, from rudimentarily managed forest groves to attract wild game (Posey, 1985) and selective extraction of non-timber forest products (Butler, 1992) to more intensive management of single species, such as açai palm (*Euterpe oleracea*) (Brondizio, 2008) for commercial purposes.

Brondizio and Siqueira (1997) argue that calling some agroforestry producers *forest extractivists* masks their social position as peasants and their agency in building farming knowledge. The authors propose that *forest farmer* better describes their active role in developing sustainable, commercial production systems and highlights their rights to market access and agrarian policies. In this paper, we follow a similar perspective but in a different context, in which farmers shift from conventional monocrop production to an agroforestry system.

2. Study Area

We address the process of co-producing an agroforestry system by melding multiple knowledge sources in Tomé-Açu, a typical old frontier town located in the Eastern Amazon. Located approximately 250km south of Belém (**Figure 1**), Tomé-Açu has approximately 60,000 inhabitants and its regional economic history is based on natural resources (Mattos and Uhl, 1994; Barros and Veríssimo, 1996). Consolidated land tenure and land-use practices in this old frontier town contrasts with

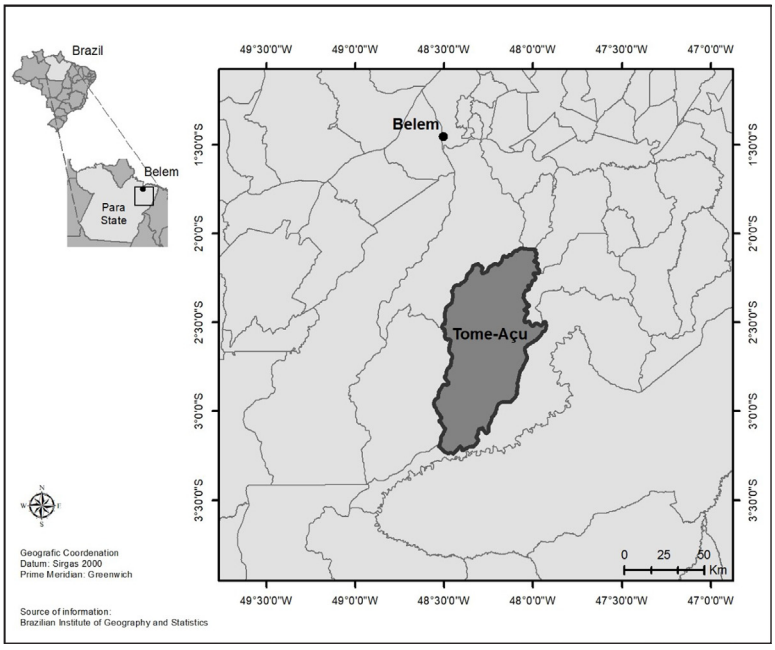

Figure 1: Map of the Tomé-Açu micro-region (Pará, Brazil), Eastern Amazon (prepared by N.M. dos Santos, 2020).

the logging-pasture-farming land-use succession often observed at Amazonian frontiers (see e.g., Schmink and Wood, 1992; Simmons, 2004). However, the region is also marked by dynamic land-use changes. Recent national policies have diminished cattle ranching and logging, while expanding oil palm. These policies include environmental regulations and improved monitoring systems to control deforestation and illegal logging. Oil palm reflects a national program to promote biodiesel production (see Brandão, Castro and Futemma, 2019). These 'frontier' land-use systems co-exist with three local farming systems. Slash-and-burn farming is an indigenous method based on cutting and burning secondary vegetation to grow annual crops such as manioc, corn, beans, watermelon and squash. Home gardens are traditional agroforestry systems based on irregular combinations of fruit and perennial species (**Figure 2A**). In addition, commercial agroforestry, the focus of our analysis, is an outcome of combining indigenous and migrant farmers' knowledge with technical knowledge from research and technical assistance (**Figure 2B**).

The rural population comprises a few traditional communities, and migrant farmers. Communities include riparian and indigenous groups living in small family clusters along rivers and in forests. Some have been granted collective territorial rights. Migrant farmers are either mid-scale or small-scale farmers. Mid-scale farmers are descendants of Japanese migrants who arrived in the region in the 1930s as part of a colonization project (Piekielek, 2010). Their original settlement, a district of Tome-Açu, is now surrounded by their commercial agroforestry fields. Their community currently comprises approximately 300 families, many holding farm properties of 100–200ha.[1] Despite this community's small size, they hold prominent political and economic positions in the municipality, from business owners to local governmental officials. Small-scale farmers are descendants of migrants from northeastern Brazil who arrived in different periods – during the 1950s to work for the Japanese migrant farmers, during the 1970s attracted by agrarian settlement programs (Callo-Concha and Denich, 2014), and more recently attracted by job opportunities in oil-palm fields (Brandão, Castro and Futemma, 2019). Those who have settled in the region hold land from 25–50ha. The three farmer groups hold different levels of assets and occupy different social positions. Long occupation by traditional farmers (indigenous and riparian communities) contrasts with one century of occupation by mid-scale Japanese migrant farmers, and more recent history of migrant small-scale farmers in the region. In particular, mid-scale farmers enjoy a privileged position in the region as local elites and as protagonists in designing an innovative agroforestry system.

3. Methods

This research is based on long-term research spanning nine years. Data were collected during six joint fieldwork visits between 2011 and 2019, lasting between two to four weeks each. Regular trips allowed us to develop an ethnographic perspective and follow gradual changes over time. They helped us to build trust with local actors and increase access to information, cross-check information and refine our dataset. We gradually enjoyed closer contact with research participants as they felt more comfortable with our presence and conversations.

Empirical data were collected through interviews, visits to farming sites, and participatory observation in local events. We used the snowball method to identify and select relevant organizations and research participants according to their level of engagement in agroforestry knowledge co-production. We considered knowledge related to producing, processing, administering and marketing agroforestry products. We conducted over seventy semi-structured interviews with one or more representatives of each relevant group. Questions included their socioeconomic context, practices, interactions and perceptions on AFSs. Thirty-seven interviews comprised organizations such as research centers[2] (6), governmental agencies[3] (10), non-governmental organizations[4] (4), grassroots organizations[5] (8), technical assistance offices[6] (3), and oil/cosmetic companies[7] (6) in the state capital of Belém and in Tomé-Açu. Several organizations were visited multiple times. Interviews took place in their offices. In addition, we held interviews with twenty agroforestry farmers (small- and mid-scale farms), fourteen oil-palm growers (small-scale farms), and five technical assistants.

We visited relevant AFS sites, such as a plant nursery, experimental sites, and rural development projects. In particular, over forty small- and mid-scale rural properties were visited in several rural villages of the

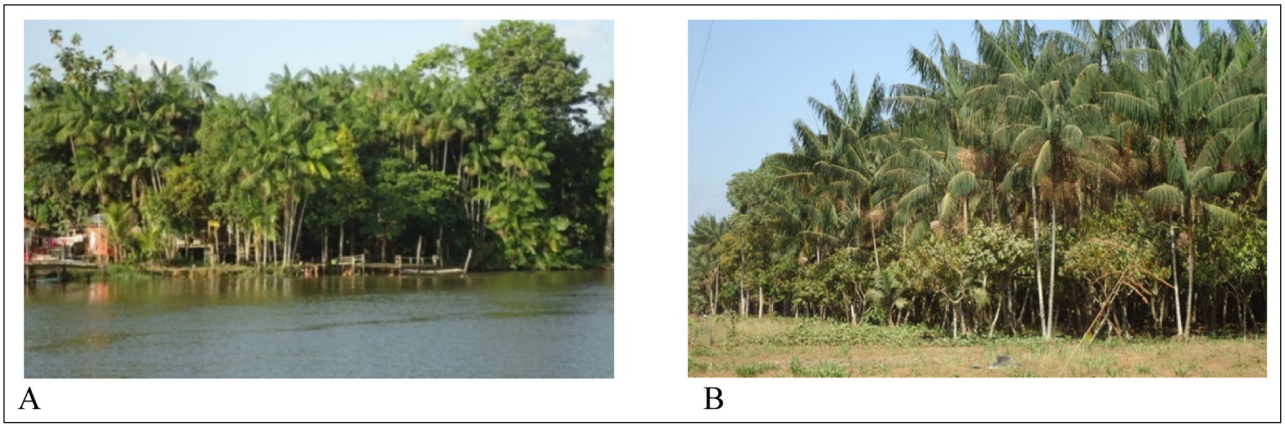

Figure 2: Agroforestry Systems in Tomé-Açu – **A)** Traditional home gardens; **B)** SAFTA model (photos by the authors).

region, where we observed different farming systems. Finally, we participated in four locally organized seminars on agroforestry (2011, 2013, 2015, and 2018) attended also by a range of local and outside stakeholders in agroforestry systems. During the two-day events, we attended presentations and discussions, and informally chatted with several participants about their practices, interactions and perceptions on AFSs.

We avoided recording interviews and chose to take written notes, following free and prior informed-consent procedures. Names of people and organizations are protected in this paper unless information was obtained from publicly accessible sources. Daily discussion between both co-authors helped to reflect on the data and to plan new visits and interviews. Field notes from both authors were shared and cross-checked in order to improve the information's detail and accuracy. The dataset was analyzed through a labelling system consisting of ways that AFSs in the region co-produce knowledge, such as history, production, interactions, practices, policies, perceptions, initiatives, and others.

4. Agroforestry Knowledge Co-Production

4.1. Safta Emergence

The agroforestry system of Tomé-Açu (SAFTA) grew out of a farming crisis experienced by the Japanese-descendant farmers. During their eighty years of settlement history, this farmer group has experienced prosperity and collapse of a series of monocrop systems. When they first settled in Brazil in the late 1920s, cocoa (*Theobroma cacao*) monocrop fields were ruined by a pest outbreak. In the late 1930s, black pepper was introduced in the region by one of the farmers and, between the '50s and '60s, they became the world's largest pepper producers (Brondízio, 2012; Flohrschutz et. al., 1983; Piekielek, 2010). Their black-pepper fields were hit by a pest outbreak in the late '60s, driving many affluent farmers into bankruptcy (Konagano, 2017). In the 1980s, another pest outbreak devastated most of their oil-palm fields. These episodes remain part of the Japanese descendant farmers' collective memory and are used as evidence to explain how they reached the conclusion that monocrop farming systems are unsuitable for the tropical context.

Their farming cooperative (CAMTA)[8] played a central role in the shift from monocrop to multi-crop farming systems. Created in 1949, this organization has evolved through those recurrent challenges (Homma, 2004; Piekielek, 2010) by continuously adjusting their strategies and generating new knowledge (Brondízio, 2012; Piekielek, 2010). Interest in agroforestry practices was first expressed by one cooperative leader. Despite his academic background in agronomy, he had a vision for solving their problem, found in traditional farming knowledge. He travelled around the region to learn from local farmers about farming practices compatible with the tropical environment (Venancio, 2019) and, in the 1970s, the cooperative set out to develop the Agroforestry System of Tomé-Açu (SAFTA).

SAFTA is a well-structured, flexible farming model. It can work with multiple field designs and significantly vary in size, from less than one hectare (for small-scale farmers) to over one hundred hectares. Species composition is based on three species types: of annual, semi-perennial and woody species, which mimics forest succession. One or two leading crops of high commercial value usually dominate the field. They are usually semi-perennial species, such as açaí (*Euterpe oleracea),* cocoa (*Theobroma cacao*), cupuaçu (*Theobroma grandiflorum*), and black pepper (*Piper nigrum*). Complementary species include a variety of tropical fruits and tree species to produce oil, resin, and timber. Young fields are more open, with sparsely distributed plants, whereas older fields feature tall trees and a multi-layered canopy (**Figures 3A** and **3B**).

A set of agrarian, ecological and economic principles guides farming consortia design, based on a combination of Amazonian and Japanese farming practices. Information on crop species, composition, production cycles, soil structure, and microclimate observed in local farming systems were combined with farming techniques and practices introduced by Japanese migrants such as pruning, budding, seed selection, and a plant nursery. Multi-crop fields are planted in regular lines, interspersed

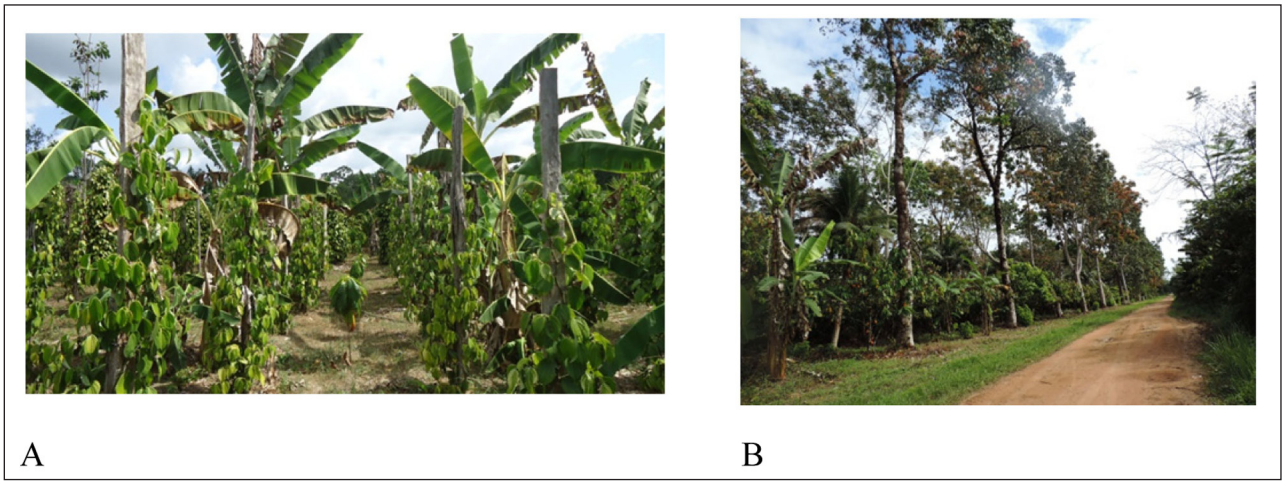

Figure 3: SAFTA fields. **A)** Young field composed by annual crop (Banana), semi-perennial crop (black pepper – leading and cupuaçu), and perennial species (andiroba); **B)** Old field composed by annual (Banana), semi-perennial (cocoa – leading) and perennial species (andiroba) (photos by the authors).

with annual, semi-perennial and perennial species. According to one farmer, this linear structure, inspired by the Japanese concept of tripod structures used to protect against earthquakes, facilitates their farm management and protects against pest outbreaks. In addition, the SAFTA principle of productive landscape mosaics resembles traditional *satoyama* landscapes in Japan (Brondizio, 2012).

Farm techniques are also grounded in Japanese culture. On individual farms, systematic observation, measurement and analysis supported their farming experiments in agroforestry fields. Their meticulous attention to detail and endurance are rooted in cultural principles of excellence, referring to technical skills in a particular field and to the highest human value manifested in all spheres of life (Befu, 1971: 173). Collectively, knowledge sharing is embedded in cultural values of community life (Sakurai, 2007: 283–292; Befu, 1971). The farmers' cooperative, cultural associations, and multiple social arenas have supported the cohesive social structure that helped disseminate successful experiments (Futemma, Castro and Brondizio, 2020).

Farmers' claims of improved environmental and economic outcomes have been confirmed by several academic researchers. Yamada (1999) and Batistella et al. (2012) demonstrate how ecological synergies among crop species, soil and microclimate features increase productivity, biodiversity and carbon storage. Piekielek (2010) reports improved economic return from year-round production and lowered economic vulnerability by combining short-, medium- and long-term income. Although ecological resilience and sustainability are major pillars of SAFTA, mid-scale farmers seem to be driven mainly by economic motivations. They are farmers with aspirations for high commercial-value crops, and access to export markets. They emphasized in several interviews their entrepreneurial standpoint, and the role of sustainability as a supporting element for their farming system's economic performance. This perspective contrasts with most Amazonian AFS models, which are usually grounded in food-sovereignty and agrarian-justice narratives.

Mid-scale farmers' knowledge of technology, marketing, fund raising, and organizational management was vital to galvanize their farming knowledge and consolidate the SAFTA model in the last two decades. We describe this process in the next section.

4.2. Safta Consolidation

SAFTA is characterized by continuous knowledge-building from research and experimentation. These fields are arenas of social interaction in which multiple farming knowledge sources are integrated. Farmers report more than two hundred SAFTA field designs. Improvements in production and marketing have led to development of new farming techniques, products, and markets. The farmers' cooperative (CAMTA) is of particular relevance in this process. This collective is the heart of SAFTA production and marketing, where 160 members (mostly mid-scale farmers) and over a thousand other registered farmers market vegetable oil, cocoa beans, black pepper and fruit pulp, with capacity to process 14 tropical fruits (Konagano, 2017). The cooperative is a node in a network of local and external partners in research, production, marketing, organizational and policy development (Futemma, Castro, Brondizio et al., 2020).

The SAFTA model has become broadly recognized in scientific, policy and entrepreneurial circles. We have identified a growing body of academic and gray literature on farming techniques, and ecological and economic assessment of this agroforestry system, a number of funding organizations supporting this initiative (e.g., JICA, USAID, FAO), and several awards granted by national and international organizations.[9] SAFTA is featured in their partners' promotional material (e.g., calendars and banners), in international documentaries, and portrayed on local and national media. The increased visibility and public recognition of SAFTA has helped legitimize this farming knowledge and set the stage for gradual institutionalization. CAMTA has applied for a Protected Designation of Origin (PDO) certification, and SAFTA has recently been formally recognized as reforestation technology under national environmental legislation. This has opened up new opportunities for small-scale farmers to apply for low-interest agroforestry credit from a national program previously targeting forest plantation projects (PRONAF-Floresta). An interview with two technical assistants revealed that approximately 200 AFS projects were expected to be implemented in the municipality under this credit program in 2018. This figure topped any other credit line for small-scale farmers in the municipality.

The SAFTA model has also consolidated as a basis for building agroforestry models. The agroforestry system to grow oil palm (*Elaeis guineensis*) is a case in point. This innovative farming system was demanded by a cosmetics company committed to sustainable supply chains. The company wants to replace conventional palm-oil monocropping (associated with high environmental degradation) by sustainable production systems (Qaim, 2020). The company approached several Amazonian suppliers to explore the possibility of developing an agroforestry system for oil palm. According to the company's research coordinator, CAMTA was selected for this collaborative project because of their previous experience with oil-palm growing, AFS systems knowledge, suitable location and strong social organization.

The Oil Palm in Agroforestry Systems Project (ASF-Oil Palm)[10] was launched in 2008 as a formal partnership among four organizations. The cooperative contributed their SAFTA knowledge and farmland, the cosmetics company pitched in with their infrastructure, financial support and entrepreneurial knowledge, and a national agricultural research agency and a federal university brought in their technical knowledge on agroforestry and forest ecology. This project differed from usual rural development programs and technology transfers by including local farmers in the design phase and building knowledge on equal grounding. However, a few project participants explained that initially the project had to overcome disagreements over different views regarding sustainable production. Farmers' demand for chemical inputs to complement soil-nutrient deficiencies clashed with demands by researchers and

the cosmetics company for a fully organic production system. Researchers' ecological efficiency goals clashed with economic efficiency motivations for farmers and the cosmetics company. Farmers initially rejected researchers' agroforestry design proposal, claiming it was not in line with SAFTA principles.

Farmers explained that, although this initial phase was not "tension-free", it was an important learning process to build a common foundation for collective decisions. AFS–Oil Palm design reconciled the company's demands for an organic supply chain with farmers' demand to follow SAFTA principles. Three six-hectare experimental units were implemented on land owned by mid-scale farmers. Between 81 and 99 oil-palm trees were planted with other SAFTA crops and fertilizer species (**Figures 4A** and **4B**).[11] Transdisciplinary discussions and solid farmers' contributions to the AFS-Oil Palm design illustrate the symmetrical relations among partners in knowledge co-production. Farmers' knowledge is also formally recognized in publications on different experiments, where they appear as co-authors together with the research team (see Castellani et al., 2009; and Kato et al., 2009). Preliminary results presented in these articles show improved ecological services, such as increased biodiversity, presence of pollinators, soil nutrients, microclimate, and higher productivity in the experimental AFS-Oil Palm fields (Castellini et al., 2009).

In sum, SAFTA has consolidated as a forum for ongoing knowledge co-production. General principles provide a flexible structure for endless experimentation and creativity, including new species such as oil palm. This open-knowledge system can be adopted by different farmers' groups in the region, who can adjust it to their particular context. In the next section, we describe how this farming system has been adopted and adjusted by small-scale farmers.

4.3. Safta Adoption

SAFTA's successful outcomes have inspired small-scale farmers in the region to adopt this farming system. Those working for mid-scale farmers were the first to try it out. They applied, on their own properties, the principles and techniques they learned in their work and everyday interactions with SAFTA farmers.

Among several small-scale farmers we have interviewed, two have been particularly successful in this process. One has become a supplier for an international cosmetics company, after investing in constructing a private oil-processing plant. The other has become a supplier for CAMTA, after developing a successful cluster of SAFTA fields on his property. These two farmers represent an emerging farmer group, who enjoy increasing autonomy in their farm system, including the way they have engaged in contract farming of oil palm. This formal partnership is supported by a national program to include small-scale farmers in the biodiesel supply chain (Brandão, Castro and Futemma, 2019). Based on a contractual agreement, farmers are required to follow strict guidelines, which include growing monocrop oil-palm fields averaging 143 plants on 10 hectares.[12] Although oil-palm tree density in monocrop fields is similar to that of the AFS-Oil Palm, adding other crops in the field was not allowed. Despite this restriction, both farmers decided to add SAFTA species (e.g., *cupuaçu*, *açaí* and cocoa) in a small part of the field. According to them, their motivation to carry out this 'experiment' was to test oil palm's viability in an agroforestry system. After five years, both farmers stated that they observed no difference in tree development between oil palm grown in the multi-crop plot and the monocrop field. During our visit to their fields, we could not identify any visual difference between oil-palm trees in the two plots. Moreover, they contend that their overall income per hectare in the experimental part is higher, from additional production of complementary commercial semi-perennial crops.

Farmers' resistance to monocrop oil-palm fields is not only influenced by the SAFTA model. Multi-crop farming system is part of traditional farming practices carried out by small-scale farmers. Some farmers not engaged in SAFTA cultivation also ignored the palm-oil company's guidelines. They argued that the distance between oil-palm trees (9m) was 'wasted space' which could be filled in by other crops. Instead of semi-perennial, commercial crops, they added traditional annual subsistence crops,

Figure 4: Experimental plot of AFS-Oil Palm (SAF-Dendê) designed by Japanese descendant farmers in collaboration with external partners. **A)** Oil palm trees interspersed with other annual and semi-perennial species; **B)** Line of fertilizer species between the oil palm trees. (photos by the authors).

such as manioc, corn, watermelon and beans. During our interview with some of the small-scale farmers, they argued that annual crops in the early years do not affect oil-palm trees' development; in some cases, they can even enhance soil quality. Conflicting views over the monocrop design for oil-palm fields were negotiated with oil companies, with technical assistants playing a key role. Companies' technical assistants are usually farmers' children who are trained at regional technical agriculture schools (Braga and Futemma, 2015). Their background, combining technical knowledge with traditional farming knowledge from their parents, enabled them to bridge the different approaches.

In our interview with one company's technical assistant, he explained that he did not report intercropping practices to the company because of the farmers' reasonable justification. He monitored the fields and, based on the results, he advised the company's managers to endorse this practice. As a result, intercropping with annual subsistence species in oil-palm fields was approved during early years palm growth. Moreover, this practice was officially encouraged by the oil companies, as illustrated by their promotional material (**Figure 5**). In our interview with one oil company's manager, it became clear that this move was part of the companies' strategy to counter criticisms against oil-palm expansion claiming this increased food insecurity among farmers.

In sum, SAFTA knowledge has been assimilated by small-scale farmers as a farming structure and principles. Including SAFTA fields in farmers' repertoire led, in some cases, to integrating them into sustainable supply chains. Integrating SAFTA's principles led to oil-palm cultivation in multi-crop systems, which have been easily incorporated into small-scale farmers' repertoire because they fit well into their traditional farming practices. Independent adoption of the SAFTA model by small-scale farmers, however, has been slow. Farmer's decision to adopt agroforestry systems is shaped by a range of factors, such as risk, household preferences, assets, market incentives, and biophysical access (Mercer, 2004). Although SAFTA addresses most of these factors, risks regarding time investment and available assets seem to be the main factors refraining farmers. CAMTA is currently engaged in a range of initiatives to address these limiting factors. As highlighted by Mercer (2004), adoption is a process that occurs over time, and just began in Tomé-Açu. In our visits to many small-scale farmers' fields, we have observed, that although many have not yet adopted SAFTA, some principles (lining up, tripod) are applied in their traditional farming systems.

5. Discussion

SAFTA is built on Amazonian indigenous farming knowledge combined with farming and commercial knowledge brought in by Japanese migrant farmers, and technical agroforestry knowledge brought in by academics and rural extension agents. **Figure 6** summarizes multiple knowledge integration processes as the SAFTA model emerged and consolidated. Initially, indigenous farming knowledge was appropriated by mid-scale Japanese-descendant farmers to overcome challenges faced in their commercial farming system. Built on home-garden principles, and reinforced by Japanese farming techniques and managerial and entrepreneurial skills, mid-scale farmers have transformed a traditional subsistence system into a commercial, multi-crop farming system. Grounded in farmers' strong organization, supported by a market-oriented cooperative, SAFTA knowledge has been consolidated in the region, branching out into innovative oil-palm growing in agroforestry systems and spilling over among small-scale farmers. SAFTA emerged by integrating two local farmer groups from different social and cultural backgrounds, challenging the clear-cut local versus non-local knowledge divide. Likewise, consolidating and developing new agroforestry systems for oil palm, based on SAFTA, challenges the clear-cut divide between

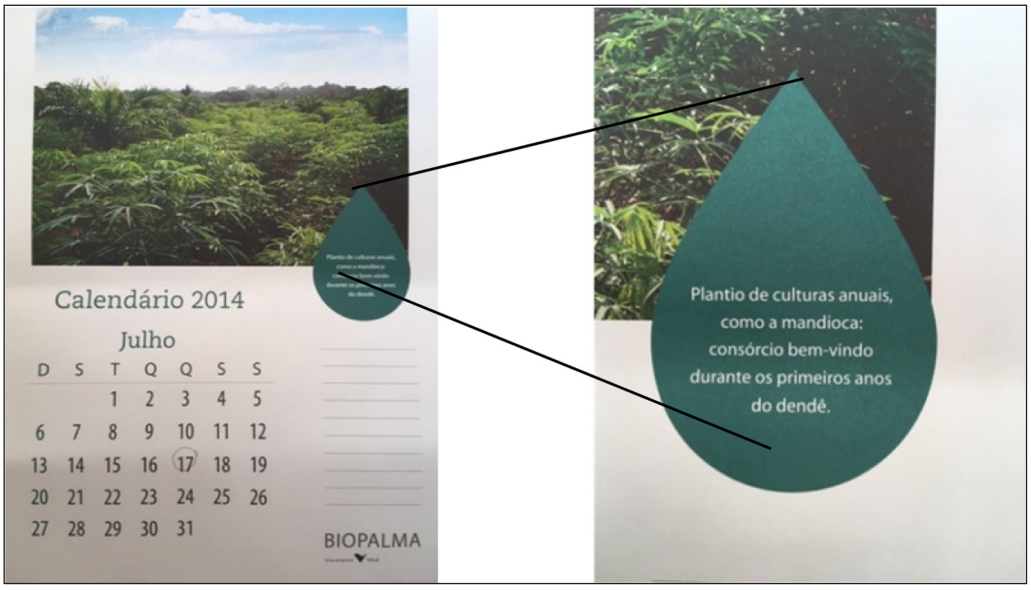

Figure 5: Calendar from an oil company featuring intercropping of oil palm with cassava (Manihot esculenta) and a close up of the text. It reads, 'intercropping with annual crops such as cassava: consortia during the first years of the oil palm field is welcome'. (photos by the authors).

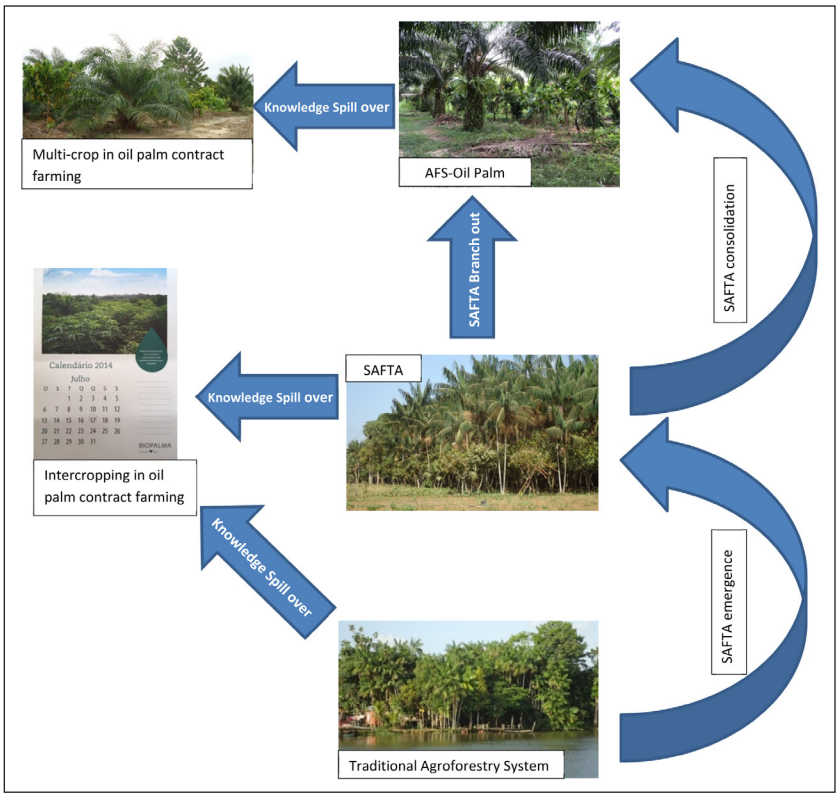

Figure 6: Farming knowledge blending and articulation.

traditional and academic knowledge. A focus on social structure and interactions is required to better understand these transdisciplinary, transcultural encounters.

Social heterogeneity is an important aspect of the SAFTA model, as the leading role of mid-scale farmers privileged their position in this process. However, instead of reproducing local inequalities, their actions have enabled small-scale farmers to access new farming opportunities. Flexible farming principles facilitate their assimilation into small-scale farming systems. They enable imagination and freedom to design farm fields according to different assets (e.g., labor force, biophysical features, available land, seeds/seedlings) and motivations (e.g., market demand, price, individual preferences). In our visits to a few properties, small-scale farmers expressed strong attachment to their SAFTA fields. They presented their consortia designs with pride as their personal creation and achievement. This emotional dimension is particularly relevant for this farmer group who has long been marginalized and devalued by policy makers and large-scale farmers. Increased self-esteem and self-confidence are important intangible values of SAFTA, which keep farmers motivated to develop and assimilate new techniques, test inclusion of new crop species, and share their experiences and results with others.

Different social positions, however, led the two local farmer groups to take different co-production paths. Under oil-palm expansion, driven in the region by national policy, both small- and mid-scale farmers were agents in co-producing oil palm in agroforestry systems. Small-scale farmers, constrained by a contract-farming scheme, co-produced with technical assistants a multi-crop oil-palm field based on intercropping with annual subsistence crops. A couple of small-scale farmers who had access to SAFTA knowledge went one step further, to co-produce multi-crop oil-palm fields based on semi-perennial cash crops, in collaboration with SAFTA farmers. Mid-scale farmers, on the other hand, who had access to additional labor, institutional support and farmland, were able to collaborate with external partners for experiments to innovate oil-palm growing in agroforestry systems. Cooperative social organization, entrepreneurial mindset, and individual tenacity have enabled mid-scale farmers to remain open to continuously assimilating new knowledge from external partners without losing their autonomy in co-production.

SAFTA grew out of a complex integration of knowledge sources. Despite the central position of traditional farming knowledge in this process, a focus on this knowledge source masks the diversity of knowledge holders and their interactions in co-production. In frontier settings, in particular, where migrant farmers from different regions settle and interact with each other and with local and external actors, boundaries between localized and de-localized knowledge sources can blur. Close interactions among multiple farmer groups and external actors make room to continuously create, integrate and re-signify. Therefore, shifting the analytical focus from pre-defined categories (local/non-local, traditional/modern) to the mechanisms integrating multiple knowledge sources in co-production can help better understand farming knowledge co-production in practice.

6. Conclusions

The SAFTA model is a transformative farming system in a forest frontier dominated by large-scale land-use systems. It has emerged from knowledge co-production among local farmers from different cultural backgrounds and has consolidated by incorporating new knowledge from external actors. This reveals how integrating indigenous knowledge with other knowledge sources can overcome hegemonic farming systems. SAFTA farming knowledge has spilled over to small-scale farmers as they work for and interact socially with SAFTA farmers and has branched out into an innovative agroforestry system for oil-palm cultivation. This process has potential for major rural landscape changes. When small-scale farmers in the region adopt agroforestry systems, they can transform monocrops, pasture land and slash-and-burn farming systems into forest-like multi-crop farm systems. In addition to land-cover change, SAFTA also generates intangible outcomes such as self-esteem, autonomy and empowerment among the rural population.

The central position of mid-scale farmers in this process sheds light on co-production political implications in contexts of social heterogeneity. This local migrant-farmer group represents a local elite who focus on commercial farming. They have lived in the region longer than migrant small-scale farmers and have a strong sense of belonging to their settlement. They strive for local development and collective wellbeing by disseminating the SAFTA model (Futemma, Castro and Brondizio, 2020). Under this particular context, power-structure enhancement expected from the critical perspectives over co-production (Turnhout et al., 2020) does not seem to have materialized in Tomé-Açu. Despite cultural, economic and political differences, all farmer groups seem to mutually benefit from the SAFTA. Rather, mid-scale farmers' privileged position has enabled them to maintain their autonomy. As a result, SAFTA has reconciled social, economic, and environmental goals, and has remained a socially inclusive farming system.

Key individuals with vision nurtured co-production by developing innovative ideas, partnerships and inspiration, also. The farming-cooperative leader who traveled around the region to learn about traditional farming practices overcame the 'traditional'/'modern' farming divide and re-signified the meaning of home-garden practices as a potential commercial agroforestry system. SAFTA farmers who inspired small-scale farmers to adopt this system on their own properties have bridged social and cultural divides between different migrant farmer groups. The cosmetics company researcher who envisaged a model for oil-palm cultivation in an agroforestry system breached the producer/buyer divide and promoted co-production of an agroforestry system for a crop associated with major socioenvironmental impact worldwide. The technical assistants who integrated farmers' and oil company's demands broke the traditional/technical divide of rural development projects. Therefore, collective actions and partnerships have been galvanized by inspiring individual initiatives, who have inspired others.

Finally, external partners' recognition of SAFTA knowledge as legitimate farming expertise is particularly essential. The divide between local and non-local knowledge sources is usually rooted in normative interpretations of time, space, and epistemic boundaries. This perspective tends to essentialize local farmers and emphasize that local knowledge is relevant only to address local problems, in contrast with technical knowledge, which is legitimized as replicable, testable power. In this paper, we show that integrating knowledge from multiple local practices, scientific research, and entrepreneurial/technocratic procedures can generate sustainable commercial farming practices accessible both to small- and mid-scale farmers. We contend that moving away from space-time conceptualizations of farming knowledge can better understand farm knowledge co-production as everyday practice in rural landscapes.

In sum, an analytical shift toward social interactions among knowledge holders is needed to better understand the dynamics of knowledge co-production. Whether co-production will lead to reinforcing or deepening asymmetrical relationships, or to empowering local farmers, will depend on how knowledge and practices are integrated among different knowledge holders, and in particular, how local marginalized actors are included in the process. The SAFTA experience indicates that mid-scale farmers may play an important role in co-producing more inclusive, sustainable farming systems in order to resist the expansion of hegemonic farming systems based on large-scale monocrop systems along Amazonian frontiers.

Notes

[1] In some cases, land properties can reach up to 500ha.
[2] Universities and research centers.
[3] Municipal secretaries, national and state agrarian agencies.
[4] International, national and regional environmental NGOs addressing conservation and agrarian issues.
[5] Rural unions.
[6] State and private rural technical assistance.
[7] Biopalma and BBB.
[8] From Portuguese 'Cooperativa Agrícola Mista de Tomé-Açu'.
[9] Successful Production Practice and Institutional Management and Sustainable Business by the National Government, Responsible Entrepreneurship by the National Bank, International Cocoa Award by Cocoa of Excellence, and Sustainable Social Technology by the National Funding Agency for Innovation and Technology.
[10] From Portuguese, SAF-Dendê.
[11] 13.5 and 16.5 oil-palm trees/ha according to two different experiment designs.
[12] 14.3 oil-palm trees/ha.

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Both co-authors made substantial contributions to conceiving and designing the work, to acquiring, analyzing, and interpreting data. Fabio de Castro developed the outline, drafted the work, and has carried out the revisions; Celia Futemma has written complementary sentences and revised the text critically for important intellectual content.

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