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ORIGINAL ARTICLE

Proximities and the role of relational networks in innovation: The case of the dairy industry in two villages of the "green municipality" of *Paragominas* in the Eastern Amazon

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Abstract

In this paper, we seek to identify the dynamics of change and innovation at work in the agricultural sector of the Brazilian Amazon region, which operate in a context of environmental and technical pressure. We search for understanding how different innovative practices are implemented and how hybrid practices can develop through relationships between local actors who belong to different worlds. Our study focuses more specifically on dairy production in the *Paragominas* municipality, whose "green municipality" programme has led to an intensification of agricultural production and a significant reduction in deforestation, and where different forms of agriculture coexist. The dynamics of interaction are explored through an analysis of social networks, in which we examine, from empirical data, the structure of networks that facilitate interactions. Through an analysis of proximity relationships, we perform a detailed study of the spatial and non-spatial determinants of these interactions. The paper first presents the study sites and analysis methods, then we provide a description of our results concerning innovation models, stakeholder networks and proximity relations.

KEYWORDS

Amazon, dairy production, innovation, proximity relations, social networks

1 | INTRODUCTION

In Brazil, a dualistic view of agriculture prevails (Favareto, 2016; Pierri, 2013). On the one hand, corporate farming (traditional, entrepreneurial and capitalist) produces for the export market, and on the other, small-scale family farming produces for the local market. Thus, beyond a complex diversity of farming systems, two models of agricultural production are identified in the literature on this topic (Hervieu & Purseigle, 2015; van der Ploeg, Ye, & Schneider, 2015) and (co)exist. The first is based on intensive farming practices and large land holdings and involves a technology-based approach with large land parcels, where technological innovation is based on the use of chemical inputs and mechanization. Coexisting alongside these large farms, are small farms, whose production is based on an entirely different model characterized by small plots of land and a low level of mechanization, and where innovation is often based on diversified crops and intense exchanges and collaborations between local producers.

These two models relate differently to innovation processes. The first is based on conventional technological innovations that have already been tried and tested in other regions, or on other crops, but which have well-known negative impacts on the environment and biodiversity (Fearnside, 2001). The second may, at first glance, appear more traditional and environmentally friendly. It is based on diversified production for self-consumption by the farmers' families, but it is also characterized by slash and burn practices, which can have a strong environmental impact. Technical innovations—although more modest—are also made, through an iterative adaptation of agricultural practices to the local environment (FAO, 2014), and social and institutional innovations take place through the development of networks of actors and collaborative relations (Torre & Wallet, 2016).

Furthermore, the two models are not completely separate from each other. Indeed, agricultural producers often cohabit, or even collaborate, because they operate in the same areas. Thus, the co-evolution of sociotechnical systems (Geels, 2004) and the interactions between actors on the ground appear to be means of generating innovation dynamics, through the formation of new types of relationships between distinct actors (Akrich, Callon, Latour, & Monaghan, 2002) and result in the emergence of new, more sustainable practices linked with hybridization processes. Technological innovation stems from social innovations, that is, it results from reconfiguring social relationships in order to meet a need, provide a solution or take advantage of an opportunity (Andrew, Klein, & Mohamoud, 2010; Westley & McGowan, 2017).

In the Amazon, the question of what type of farming should be supported to promote territorial development is a real issue. The development model that underlays the process of colonization and deforestation was characterized by a combination of different farming systems. Migrant peasants from the *Nordeste* or Southern Brazil would settle on a piece of land for a few years and would then clear it using slash and burn techniques and implement pastures for a time before selling them to cattle ranchers who could occupy large areas without having to make heavy investments but could benefit from the existence of structured cattle markets (Pacheco & Poccard-Chapuis, 2012). This process was associated with the transformation of the pioneer front zone—where one gained access to land by working it—into an expansion front (de Assis Costa, 2005).To this expansionist logic was then added a productivist logic, with the development of cash crop productions such as soya or oil palm and the increase of agricultural yields through mechanization or the massive use of chemical inputs.

In this paper, we seek to identify the dynamics of change and the various types of innovation at work in the agricultural sector of the Brazilian Amazon region, which operates in a context of environmental and technical pressure. We aim to understand how various innovative practices are being implemented and how hybrid practices can develop through relations between local actors who belong to different worlds. We have chosen to focus specifically on milk production in the municipality of *Paragominas*, driven by a programme of intensification of agricultural production and a significant reduction in deforestation, as well as the coexistence of different forms of agriculture and of small and large scale producers. We have chosen to examine milk production because it has engaged in a new dynamic of intensification. Indeed it requires daily and intensive pasture management. The structure of the industry depends on the development of dense enough milk production pools to ensure that milk collection rounds are optimized, which often involves different agricultural models.

The interaction dynamics are explored through an analysis of social networks, in which we examine, on the basis of empirical data (Grossetti, Barthe, & Chauvac, 2011; Lazega, 2001), the structure of the networks that facilitate interactions, and through an analysis of proximity relations whereby we perform a detailed study of the spatial and non-spatial determinants of these interactions. Approaches to agricultural development involve the analysis of social networks to identify the existing interactions at work in the dissemination of knowledge or in the agro-ecological transition (Compagnone & Hellec, 2015), whereas proximity analysis has been used to understand the determinants of these interactions. Combining both analytical frameworks to study agricultural development has more seldom been proposed (Polge & Torre, 2017).

We shall first present our sites of study while justifying our choice, before describing our analysis methods – based on an approach in terms of networks of actors and of proximity. We will then provide a description of our findings concerning innovation models, networks of actors and proximity relations.

2 | CASE STUDIES

The municipality of *Paragominas*, founded in 1965, has a surface area of 19.342 km2 and a population of over 97.819 inhabitants, almost 80% of whom are urban residents (IBGE—Brazilian Institute for Geography and Statistic, 2010). It developed into a major economic centre in the State of Pará (Figure 1). A strong and proactive municipal leadership team, supported by the main economic actors, rapidly changed the urban structure and the transport network, by, among other things, tarring roads. Promotional campaigns implemented in southern Brazil and presenting the agronomic potential of the *Paragominas* area (connections with research institutions, available land, etc.), attracted entrepreneurs invested in large-scale crop production (soy and corn) and forestry (eucalyptus and paricá), part of which is transformed locally (Piketty et al., 2015).

In the 2000s, some land holdings situated at the fringes of the municipality (Figure 2) were deemed unproductive by the National Institute for Colonization and Agrarian Reform (INCRA) and were expropriated in order to transfer sections of the land to landless farmers and give them access to public services within the agrarian reform settlements (public land for distribution to landless farmers). The establishment of these zones has led to the development of areas of diversified family farming (rice, corn, cassava, small-scale livestock); areas which have developed alongside traditional communities which have historically been home to smallholders.

We have chosen to study the interactions, within the municipality of *Paragominas*, between actors of the dairy sector located in two villages with contrasting geographical characteristics (distance to the city, state of the road network—Figure 2) and in which milk producers are organized differently (as summarized in Table 1).

The village of Mandacaru, close to the tarred road and therefore easily accessible from the city, comprises the milk supply area of a large dairy company located 60 km away. Most producers are exposed to wide price variability and irregular payments, and the dairy company's poor communication results in a lack of transparency as to its actions. The milk is stored in special tanks at the producers' premises and is collected daily (or every two day) by a truck from the dairy company. Some producers have tractors, use selective herbicides and experiment with intensification methods disseminated by institutes of technology (irrigation, silage, fertilizers, etc.) to be able to produce fodder to feed their livestock during the dry seasons, and develop production. The very high land pressure (for residential or large scale crop production purposes) pushes producers to sell their land and reinvest in other villages further away from the city, in non-agricultural activities or urban housing.

The village of Nova Jerusalem is situated far from the tarred road and the city, which makes it impossible to supply milk to dairy companies. Since 2014, the local producers have formed a cooperative, which has enabled them to centralize the transformation process and to produce cheese in compliance with food safety standards. The cooperative's indebtedness, resulting from the purchase of processing equipment and from its low cash flow, causes it to pay the producers a low but stable price. Few farmers have tractors or use herbicides, but experiments in ecological farming conducted with the support of research organizations—rotational grazing or cultivation of fodder legumes—

FIGURE 1 Location of Paragominas
Source: Etienne Polge.

have provided solutions for increasing productivity. Ensuring continued milk production depends on the cooperative's ability to increase the price paid to producers.

In terms of innovation, we faced with the coexistence of two main models.[1] The model of the large dairy companies is an intensive one, based on medium technology and on chemical sciences and experiments. It belongs to the so-called technological paradigm, promoted by large agro-business companies and locally diffused by farm advisors (McIntyre, Herren, Wakhungu, & Watson, 2009). In our case studies these new practices refer to irrigation, silage, selective herbicides, concentrate feed, animal breeding, pasture renewal. The other model, adopted by the cooperative of local producers, is based on two types of innovations. The low technological innovations are related to alternative ecological methods and diversification of production and belong to the so-called agro-ecological paradigm, locally promoted by scientific institute and researchers (Wilson, 2007). In our case studies these new practices refer to rotational grazing system, growing fodder legumes, mixed crop livestock farming. This model is also based on organizational innovation, because it involves local producers who follow learning processes through networks sharing good practices and organizational devices (Falk & Harrison, 1998).

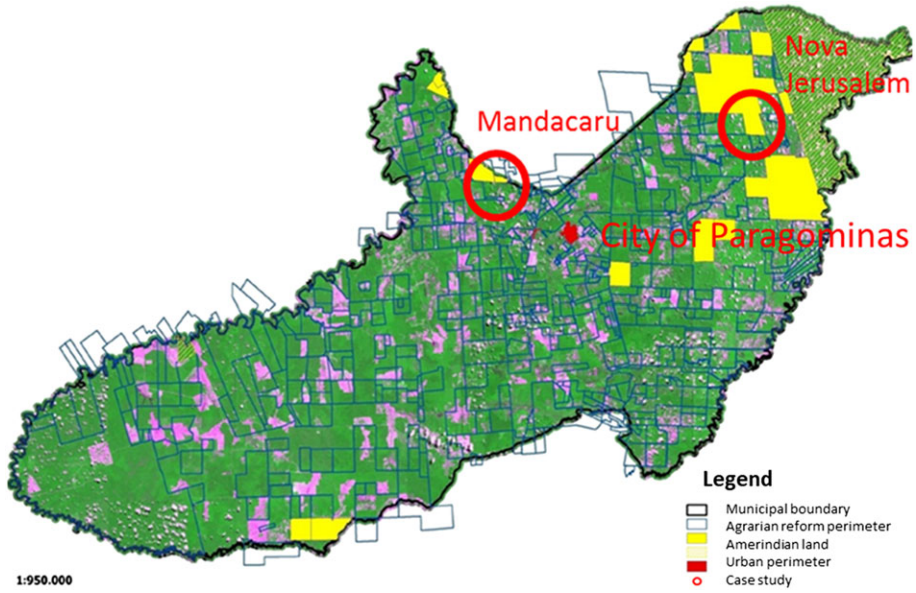

FIGURE 2 Geo-referenced properties recorded in the Rural Environment Registry of Paragominas, Agrarian reform settlements and location of the case studies
Source: Projeto Pecuaria verde (https://pt.slideshare.net/jannicemonteiro/palestra-municipio-verde-24-06-20101-adnan-demachki) and Etienne Polge.

TABLE 1 Characteristics of the villages of Mandacaru and Nova Jerusalem

	Mandacaru	Nova Jerusalem
Proximity to the city	Close (30 minutes on dirt road +15 minutes on tarred road – by car)	Far (2,5 hours of dirt road – serviced part of the year)
Collection	Dairy company	Cooperative
Remuneration	0,65–1 R$/l (December 2015)	0,7 R$/l (December 2015)
Techniques	Use of tractor and herbicides Experiments by some producers	Low use of tractors and herbicides Experiments conducted with researchers
Objectives	Economic sustainability of milk production for small scale producers.	Increase in the price of milk Sustainability of the cooperative

TABLE 2 Technical models and innovations

Models	Type of activities	Degree of intensification	Commercialization method	Innovations
Smallholders	Diversified and multiple activities	Low	*Ad hoc* deliveries	Iterative innovation processes of adaptation to the local environment (low tech and organizational)
Specialized producers	Specialized in milk production	High	Regular deliveries	Technological innovations through the dissemination of research findings and a process of adaptation to the environment
Corporate farmers	Specialized in meat production	Extensive	*Ad hoc* deliveries	Technological innovations through the dissemination of research findings

It has to be emphasized that the term innovation is taken here in its Schumpeterian meaning: a novelty in a firm, a sector or an area, provided the fact that it can be transferred from other firms, sectors or areas. We make reference to various types of innovation, and the ones considered here could be classified more as "novelties" in the sense of

(Loreto, Servedio, Strogatz, & Tria, 2017). But some of them are rather medium tech (in the large farms), involving hard technologies, and the other ones rather low tech (in the cooperative), involving users in their fabrication and their development (Hirsch-Kreinsen, 2018; Sáenz, Aramburu, & Rivera, 2009).

3 | METHOD OF ANALYSIS

In our analysis, we use a social network approach based on primary data. This approach, already tried and tested to study interactions within territorial governance systems (Polge & Torre, 2017), consists in analysing the different types of exchange between producers located in the same village and in examining how the socio-economic structure influences innovation. It also makes it possible to study how the different agricultural models co-exist and hybridize, and therefore how innovations are implemented, disseminated.

The selection of the subpopulation we have studied was based on exploratory surveys consisting in drawing up a list of producer, in each of the villages, who depend on milk production for more than half of their total income. Given the emerging character of dairy production and the isolation of the villages we have interviewed all the producers concerned by the dairy production in the two villages. Semi-structured interviews focused on the producers' life history (Grossetti et al., 2011), in order to understand how they came to settle and became involved in the village, on the one hand, and in the production system, in order to identify the types of actors, farming systems, and practices. More structured interviews comprising sociometric questions were also conducted to identify the links between the members of the sub-population studied. The aim was to collect data on interactions (who interacts with whom), their determinants and content: commercial exchanges (tractor service, pasture leasing, labour, etc.) and non-commercial exchanges (bartering, exchange of services, donations, etc.), as they were presented by the respondents.

We conducted two series of interviews. Of the 29 interviews carried out in the village of Mandacaru, 21 included sociometric questions and all 23 interviews performed in Nova Jerusalem contained sociometric questions. The missing quantitative data were inferred from information collected during the semi-structured part of the interviews. The data were then processed using Statnet, a suite of R packages for network analysis (Handcock, Hunter, Butts, Goodreau, & Morris, 2008), in order to organize them into matrices corresponding to each type of exchange, to visualize the networks and to perform statistical measures of density (number of actual relations over the total number of possible ones), reciprocity (number of bilateral relations over the total number of relations) and transitivity or clustering (reflecting a collective logic) in the different networks. Pairwise correlations were analysed using the quadratic assignment procedure (QAP – Hubert & Schultz, 1976). Identifying the direction of relations, from seller/supplier to buyer/receiver, enabled us to characterize directed networks and understand the processes of reciprocity and transitivity, and provided us with more precise structural data. Thus, we examined the degree centrality of the producers, that is, the number of interactions (incoming or outgoing) between an individual (ego) and the other (alter) participants in the network. To define the communication network we have taken into account the significant face-to-face discussions (i.e., consisting of more than just a simple Hello) with a frequency of one or more per month.

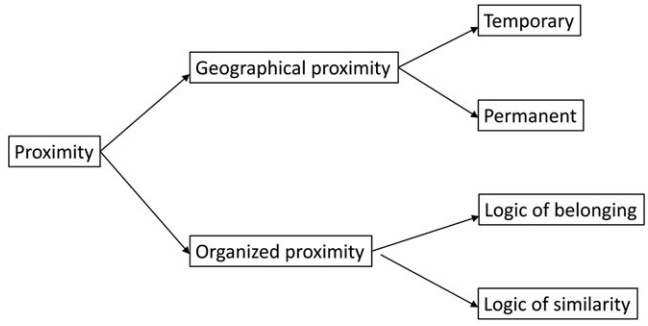

FIGURE 3 Framework of proximity analysis

In order to understand the determinants of the strategies adopted by the actors, we look beyond the mere structure of the networks and use the framework provided by proximity analysis (Torre & Rallet, 2005), which distinguishes between geographical proximity and organized—essentially non-spatial and relational—proximity (Figure 3). Thus, we have identified relations of geographical proximity between producers but also geographical proximity to the city, which facilitates interactions with other actors. This geographical proximity can be permanent—when the producers live close to the city—or temporary if they need to travel substantial distances to reach the city. In the case of organized proximity, the logic of belonging refers, in our study cases, to the active participation of actors in collectives such as associations or cooperatives within which many interactions occur. The logic of similarity refers to actors who do not necessarily know each other but adopt a similar farming model and therefore share similar references.

4 | TECHNICAL MODELS AND INNOVATION

Discussions with the respondents on production systems revealed three categories of producers, corresponding to three combinations of technical models and innovations.

Smallholders produce milk and other agricultural products (15 in Mandacaru and 11 in Nova Jerusalem). They operate small-scale diversified family farms (of less than 35 ha), use low-intensity production systems and produce mostly for self-consumption. They keep a small number of cows and the milk they produce is stored in collective tanks (Mandacaru) or is delivered to the cooperative on an ad hoc basis (Nova Jerusalem). They adopt some medium tech innovation through the paid services of other actors but develop mainly low tech and organizational innovations.

Specialized producers (11 in Mandacaru and 8 in Nova Jerusalem), who tend to run medium-sized farms (between 35 and 500 ha), adopt production intensification practices, produce fodder to feed their livestock and have suitable infrastructures to make optimal use of the farm's resources (fences, silos, etc.). They either store the milk in individual tanks or deliver it to a collective tank. They tend to follow a productivist model (selective herbicides, corn silage) but also adopt innovations, which are interesting in the Amazonian context (production of fodder in the lowlands, protein banks, pasture irrigation, etc.). Some farmers in Mandacaru sell their milk directly in town or transform it into artisan cheese when the price paid by the dairy is too low. In Nova Jerusalem, the farmers invest in the cooperative's processing tool and are in a process of intensification. Their behaviour is mainly related to medium tech innovations.

The corporate farmers run large farms (3 in Mandacaru and 2 in Nova Jerusalem), over 500 ha, and tend to specialize in meat production and large-scale crops (soy, corn), with a focus on land expansion, without seeking to intensify milk production. Their goal is to produce milk without impacting the production and sale of suckled cow, which constitute their main source of income, while producing enough milk to help maintain dairy farming in the villages and develop a profitable commerce with the other producers (buying calves at low prices and selling cows for high prices) (Mandacaru and Nova Jerusalem). Their behaviour is mainly related to medium tech innovations.

5 | NETWORKS OF ACTORS

Our examination of the communications and commercial and noncommercial exchanges between the various actors has enabled us to identify different networks of actors. For the sake of clarity, we analyse them separately for each village, in order to be able to visualize them (Figure 4 for *Mandacaru* and Figure 5 for *Nova Jerusalem*).

5.1 | Mandacaru

The face-to-face communication network (Figure 4) is dense, with a high reciprocity and a high clustering effect. It consists of two distinct, unrelated cliques, made up of smallholders on the one hand and a group of specialized farmers and entrepreneurial producers on the other. A group of producers are positioned as intermediaries. Face-to-face communications between the members of each clique take place in people's homes, at the village square or in town. Most

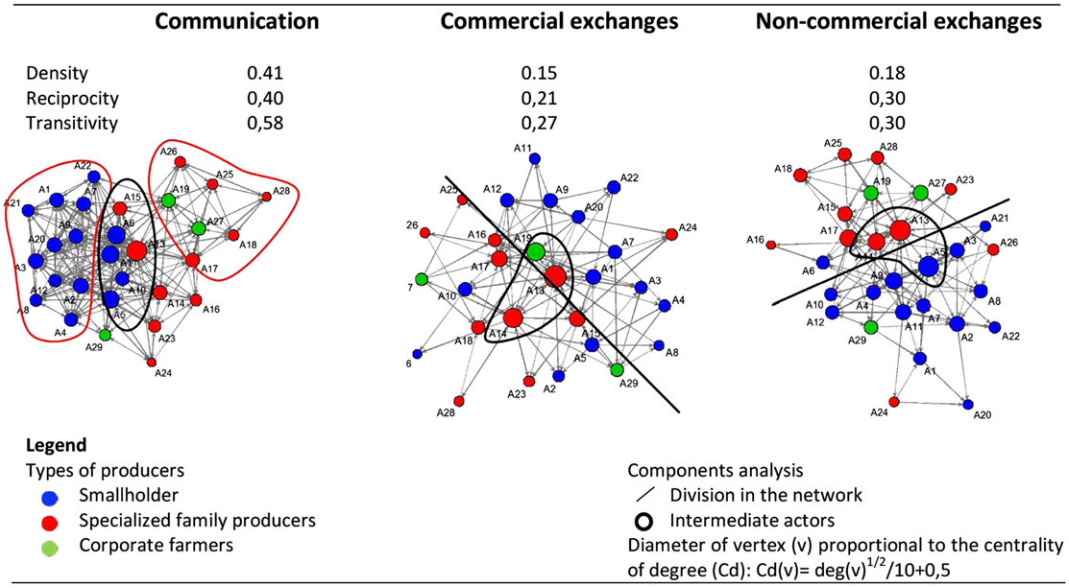

FIGURE 4 Socio-economic networks in the village of Mandacaru

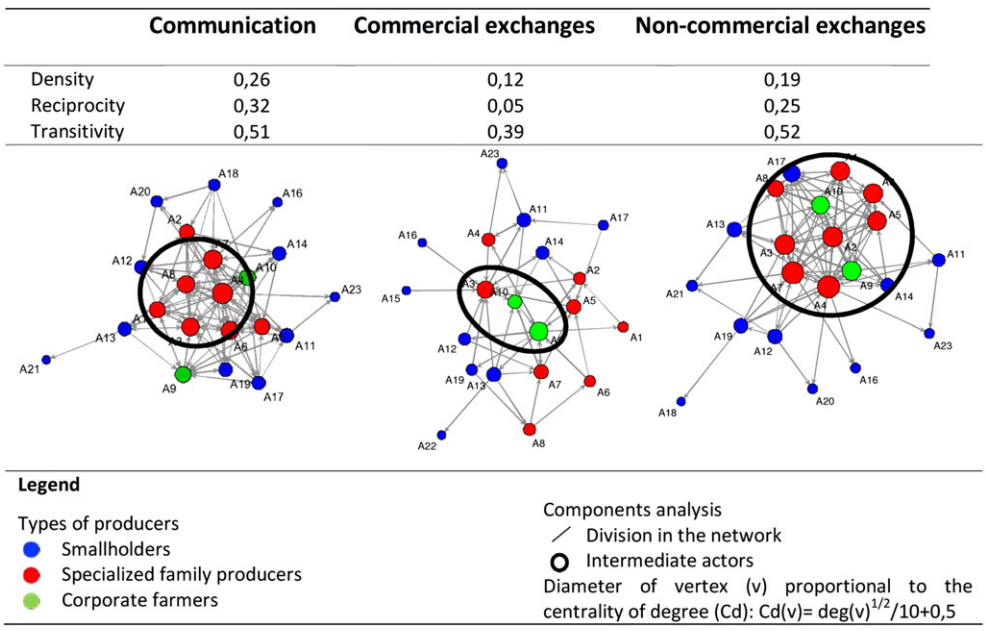

FIGURE 5 Socio-economic networks in the village of Nova Jerusalem

interactions between the members of the two cliques occur when they meet on the road, during meetings of the village association and religious services, which all types of farmers attend; the producers in the intermediary position communicate with the members of each of the two cliques, thus facilitating the exchange of information within the village.

The network of commercial relations—selling animals or land, renting equipment and pasture, paid services (sowings, soil conditioning, tractor treatments)—is sparse, in that when a farmer sells a product or service to another farmer, he seldom purchases anything in return (low reciprocity and transitivity). But these exchanges are crucial

because they enable smallholders, in particular, to sell their animals and rent their pasture to specialized producers. Trading in animals enables the latter to earn a margin and provides them with a means of commercialization. Renting pastures from entrepreneurial producer or smallholders enables them to have fodder during the dry season.

The network of non-commercial exchanges is slightly denser. These exchanges – mutual help on the farms, loan of equipment or money, donations of seeds or foodstuffs—involve reciprocity through the act of gift / counter gift, and a more collective approach (transitivity). They are essential, especially among smallholders, to cope with the peaks in workload and the scarcity of financial resources. Non-commercial exchanges are a means for smallholders and specialized producers to secure commercial exchanges, but the latter are asymmetrical and tend to reproduce relations of domination.

Specialized producer A13, whose farm is situated just outside the village along the road to town, has a tank in which smallholders store their milk and has a very high degree of centrality within the three networks (see diameter of the circle in Figure 5). The location of his farm, coupled with the fact that he is equipped with certain resources (milk tank), enables him to occupy a position of intermediary and to engage in various types of commercial activities, such as selling animals bred by smallholders to wholesalers. Corporate farmer A19 behaves similarly, although the local commercial network is not as essential to him: the income generated by the farm is mainly derived from selling his own animals to wholesalers. Specialized producer A14, on the other hand, has a high degree of centrality in that he performs mechanized tasks (ploughing, sowing, chemical treatments, silage) for other producers. This constitutes a technical evolution compared to the past when those tasks were carried out manually (slash and burn and broadcast sowing).

A13 is very central to the network of non-commercial relations through his loans of money to other farmers. Although the loan amounts are relatively small, they provide him with the opportunity to buy calves from his borrowers at a low price. Thus, he can renew his herd, resell the calves in bulk or fatten them while earning a substantial profit margin. The relations between specialized producers and corporate farmers consist more in exchanges of equipment. A19 has a less central position within the network of non-commercial exchanges, whereas specialized producer A14 and one smallholder (A5) are particularly central. The former's history is similar to that of the smallholders (immigration from the Nordeste without any capital and self-sufficiency) while the latter coordinates the activities of the members of the evangelical church and uses this network for his evangelization mission.

6 | NOVA JERUSALEM

The density, and to a lesser extent, the reciprocity and transitivity of the face-to-face communication network are lower than in *Mandacaru*. Analysis of the networks reveals a group of central specialized producers rather than a single producer, whereas the entrepreneurial producers are more peripheral.

The network of commercial relations has a very low density and low reciprocity. One entrepreneurial producer (A9) and a specialized farmer (A3) concentrate all the commercial relations. More specifically these two producers almost systematically buy calves from other farmers, sometimes via A10.

The network of non-commercial exchanges, on the other hand, is very dense, particularly between specialized producers and entrepreneurial producers (high transitivity), whereas smallholders tend to be peripheral. The interest-free loaning, mainly granted by A9, does not appear to be a significant activity compared to the situation in *Mandacaru*. These exchanges correspond in particular to the interactions generated by the cooperative.

TABLE 3 comparison of the interactions in the villages of Mandacaru and Nova Jerusalem

	Mandacaru	Nova Jerusalem
Interactions	Two distinct face-to-face communication groups (pluri-activity and specialized farmers/corporate farmers) Central and active producers Many exchanges and networks of dependence	No clique, No ultra-central actor Groups of specialized farmers play an active role in the communication Less commercial exchanges and more non-commercial interactions

The interactions between the producers in both villages about milk production can be summarized (Table 3) by highlighting that, in Mandacaru, technical exchanges and communications between different categories of producers take place through the intermediary of very central and active smallholders. In Nova Jerusalem, on the other hand, where commercial exchanges are less frequent and producers engage more in non-commercial relations, we find that no actor occupies an ultra-central position but that specialized farmers play an important role within the face-to-face communication networks.

7 | PROXIMITIES

The analysis of the information collected during the interviews reveals the proximity dynamics at work within the networks in both villages and has enabled us to identify the modes of communication and collaboration between local producers, as well as the processes of organization and dissemination of techniques at the local level.

7.1 | Geographical proximity

We have defined geographical proximity as the distance separating local actors from other people or from specific places, such as the city, for example. In *Mandacaru*, the producers are geographically located according to the agricultural models they follow. Smallholders tend to be situated at the far end of the dirt road leading to town and larger producers at the beginning, while the specialized producers are located halfway along the road. This geographical proximity explains partly the intermediary role played by some specialized producers such as A13, who take advantage of this position to interact with the other two types of producers. It plays an essential part in fostering non-commercial exchanges and facilitates communication, but more so within the cliques. Indeed, it plays a lesser role in the interactions between smallholders on the one hand and specialized/corporate farmers on the other, their relations being explained by a high degree of organized proximity between them (see below). The temporary geographical proximity also allows them to meet on a regular basis when they deliver their milk to the collective tanks and are also opportunities to communicate and to reinforce the different types of interactions. The short distance to the town enables the entrepreneurial producers to maintain relations of temporary geographical proximity with urban actors, particularly when they have means of transport, which facilitates communication, commercial as well as non-commercial exchanges with other actors.

In *Nova Jerusalem*, the spatial concentration of the farms results in a high degree of permanent geographical proximity between the different categories of producers. Moreover, the remoteness of the roads and therefore of the city (3 hours of travel on the dirt road, on slow and scarce public transport), has encouraged the producers to associate with one another and form a cooperative. The geographical proximity between them facilitates non-commercial exchanges and face-to-face communication in quasi autarky, including between smallholders and specialized /entrepreneurial producers, by enabling them to form links of organized proximity (see below). Temporary geographical proximity is also important in implementing common techniques and sharing innovations. Attending meetings and delivering their milk to the small dairy provides them with opportunities to interact, which facilitates the development of relations of organized proximity linked to the cooperative.

7.2 | Organized proximity

There are two types of organized proximity according to whether the actors are connected by a logic of belonging (participation in collectives such as associations or cooperatives) or a logic of similarity (adoption of the same agricultural model, being members of the same church).

In *Mandacaru*, the organized proximity between producers explains most of the interactions that occur between them. The logic of similarity is prevalent in that producers who belong to the same category of farmers interact primarily with one another. This dimension is reinforced by their being members of the same faith

communities (Evangelical/Catholic). However, a logic of belonging also exists between the active members of the villagers association. An attempt to create a cooperative failed, officially because of disagreements over its location. The links that form between the farmers through their faith or their involvement in the villagers' association are crucial and have contributed to developing solidarity between different categories of producers. Belonging to the same faith facilitates non-commercial exchanges, but the existence of different faiths does not seem to be a divisive factor in the village.

To better understand the links of organized proximity between local producers, we have used a quadratic assignment procedure (Table 4) to analyse the correlations between the three networks examined above (commercial, non-commercial exchanges, and face-to-face communication exchanges). It shows that communication links are weakly correlated with commercial exchanges but have a stronger correlation with non-commercial exchanges; it also reveals a weak correlation between commercial and non-commercial relations, which indicates that producers who are linked by relations of organized proximity based on a logic of belonging tend to engage more in non-commercial exchanges. Thus, face-to-face communications and non-commercial exchanges are the main means of disseminating and sharing innovations and best practices. Furthermore, the interactions between each category of farmers are limited to commercial exchanges, which reduces the number of opportunities to exchange knowledge through other types of interactions. Only a few specialized farmers engage in different types of interactions, both with smallholders and entrepreneurial producers, and are not exclusively governed by the logic of similarity.

The detailed results of the correlation analysis reveal the key part played by loans, which are correlated with many other types of linkages and are explained by a logic of belonging between producers of different categories. Those loans can generate special relationships between the lender (often a specialized or corporate farmer) and the borrower, which then enable the lender to buy animals at lower prices, to have priority when he needs to rent pastures during the dry season or to get paid for certain services. The relationships created through the loans also give rise to non-commercial exchanges such as exchanges of services or cattle, as well as gifts and mutual help. However the relation is often asymmetrical and tends to benefit the lender, particularly when it involves the purchase of cows and the sale of calves, which are highly correlated with each other. The specialized farmers sell dairy cows to smallholders at a high price, and the latter then sell them their calves at a low price in return. The gift, mutual aid and cattle exchange variables are correlated with each other and all play a key role in the functioning of the non-commercial exchange network.

As intermediaries, specialized farmers can have access to the resources of smallholders (calves and pastures) and of corporate farmers (farm equipment) and are therefore the most likely to adopt new practices on their farms. However, the exchange networks' structure is fragile, partly because of a sustained rural exodus, which makes producers—particularly smallholders—reluctant to adopt new practices to develop dairy production, which is potentially more expensive and risky (milk prices vary and dairy production involves buying animals that are more expensive than beef cattle, have less value in terms of meat production, and requires buying complementary feed whose prices are unstable).

In Nova Jerusalem, the logic of belonging is above all linked to the existence of the cooperative, which was created by various categories of producers and constitutes a hub around which the farmers meet and conduct common activities related to milk production. The producers interact and develop new practices through non-commercial exchanges facilitated by the cooperative and its activities (daily milk delivery, regular meetings, joint investments). Thus, the creation of the cooperative has generated relations of proximity, which must now be consolidated through the members' active participation in its running. Indeed, the cooperative appears, for the time being, to merely serve as a service provider, and the farmers do not seem to be totally invested in its management. Furthermore, friendships and family ties seem to play a significant part in non-commercial exchanges, which highlights the importance of the logics of similarity.

The results of the QAP test conducted between the three networks (Table 5) show that face-to-face communication relations are more strongly correlated with non-commercial than with commercial exchanges, indicating that producers who communicate a great deal with others engage more in non-commercial exchanges. This is the case

TABLE 4 Statistical correlations between the networks (QAP) of the village of Mandacaru

Communication Commercial exchanges Non-commercial exchanges	Communication	Commercial exchanges						Non-commercial exchanges					
	1*** 0.19*** 0.35***	0.19*** 1*** 0.17***						0.35*** 0.17*** 1***					
	Communication	Pasture renting	Tractor services	Labor	Sale cows	Sale calves	Other sales	Bovine exchanges	Gift	Seeds	Free services	Mutual aid	Loan
Communication	1***	0.15***	0.07*	−0.07**	0.17***	0.17***	0.09***	0.14***	0.11***	0.16***	0.24***	0.19***	0.17***
Pasture renting	0.15***	1***	0.35***	−0.02	0.12**	0.2***	−0.03**	−0.02	0.03	0.02	0.06*	0.26	0.23***
Tractor services	0.07*	0.35***	1***	0.04	0.19**	0.12**	−0.03	−0.02	0.02	0.05	0.06	0.05***	0.03
Labour	−0.07**	−0.02**	0.04	1***	0.02	0.08**	−0.02	−0.02	−0.02*	−0.02	−0.01	−0.02	−0.02
Sale cows	0.17***	0.12***	0.19**	0.02	1***	0.39***	0.09**	0.05	0	0.02	0.05	0.01	0.08*
Sale calves	0.17***	0.2**	0.12**	0.08**	0.39***	1***	0.02	−0.03**	0.01	0	0.1**	0.17***	0.15**
Other sales	0.09***	−0.03**	−0.03	−0.02	0.09**	0.02	1***	−0.03**	0.01	0.14***	0.01	−0.04	−0.03
Exchanges bovine	0.14***	−0.02	−0.02	−0.02	0.05	−0.03**	−0.03**	1***	0.16***	−0.02*	0.1**	0.29***	0.32***
Gift	0.11***	0.03	0.02	−0.02*	0	0.01	0.01	0.16***	1***	0.06*	0.17***	0.1**	0.21***
Seeds	0.16***	0.02	0.05	−0.02	0.02	0	0.14***	−0.02*	0.06*	1***	0.07*	0.04	0.02
Free services	0.24***	0.06*	0.06	−0.01	0.05	0.1**	0.01	0.1**	0.17***	0.07*	1***	0.19***	0.23***
Mutual aid	0.19***	0.26***	0.05	−0.02	0.01	0.17***	−0.04	0.29***	0.1**	0.04	0.19***	1***	0.41***
Loan	0.17***	0.23***	0.03	−0.02	0.08*	−0.03**	−0.03	0.32***	0.21***	0.02	0.23***	0.41***	1***

Notes: $N = 29$, standard deviation. ***$p < 0.01$; **$p < 0.05$, *$p < 0.1$.

TABLE 5 Statistical correlations between the networks (QAP) of the village of Nova Jerusalem

	Communication	Commercial exchanges						Non-commercial exchanges					
Communication **Commercial exchanges** **Non-commercial exchanges**	**1***** **0.37***** **0.64*****	**0.37***** **1***** **0.33*****						**0.64***** **0.33***** **1*****					
	Communication	**Pasture renting**	**Vaccine**	**Labor**	**Sale cows**	**Sale calves**	**Other sales**	**Friendship**	**Advice**	**Barter**	**Familiy**	**Mutual aid**	**Loan**
Communication	1***	0.17***	0.21***	0.22***	0.07*	0.14***	0.26***	0.6***	0.46***	0.2***	0.19***	0.23***	0.06
Pasture renting	0.17***	1***	0.12***	0.31***	−0.01*	−0.01	0.11**	0.07	0.2***	0.07**	0.12***	0.12***	−0.01**
Vaccine	0.21***	0.12***	1***	−0.02	−0.02**	0.08**	0.29	0.08*	0.15***	0.09*	0.16	0.09*	−0.02
Labour	0.22***	0.31***	−0.02	1***	−0.02	−0.02	0.08	0.17	0.14***	0.05	−0.02	0.02	−0.02
Sale cows	0.07*	−0.01*	−0.02**	−0.02	1***	−0.02	−0.02	0.04	−0.04	0.05	0.09	−0.04	−0.02
Sale calves	0.14***	−0.01	0.08**	−0.02	−0.02	1***	0.08	0.08*	0.08*	0.12**	0.09	0.08*	0.46***
Other sales	0.26***	0.11**	0.29***	0.08	−0.02	0.08	1***	0.24***	0.27***	0.2***	0.06	0.12**	−0.02
Friendship	0.6***	0.07	0.08*	0.17***	0.04	0.08*	0.24***	1***	0.49***	0.1**	−0.02	0.2***	0.03
Advice	0.46***	0.2***	0.15***	0.14***	−0.04	0.08*	0.27***	0.49***	1***	0.04	0.31***	0.29***	0.02
Barter	0.2***	0.07**	0.09*	0.05	0.05	0.12	0.2***	0.1	0.04	1***	0.16***	0.31***	0.11*
Familiy	0.19***	0.12***	0.16***	−0.02	0.09	0.09	0.06*	−0.02	0.31***	0.16***	1***	0.35***	0.19**
Mutual aid	0.23***	0.12***	0.09*	0.02	−0.04	0.08*	0.12	0.2***	0.29***	0.31***	0.35***	1***	0.07*
Loan	0.06	−0.01**	−0.02	−0.02	−0.02	0.46***	−0.02	0.03	0.02	0.11*	0.19**	0.07*	1***

Notes: $N = 23$, standard deviation. ***$p < 0.01$; **$p < 0.05$, *$p < 0.1$.

in *Mandacaru*, even though the correlation between commercial and non-commercial exchanges is stronger. Here again, non-commercial exchanges and face-to-face communications are the primary means of disseminating and sharing innovative practices. Close examination of the matrix reveals a strong relation between selling calves and loaning money, as well as between paid labour and pasture renting, which means that wage-based relationships are at work in addition to commercial exchanges. There are also strong correlations between face-to-face communications and friendships, or between family ties and mutual assistance, which is relatively common and shows the important role of the logics of similarity in how local actors organize collectively and how practices are disseminated.

8 | CONCLUSIONS

We have aimed in this paper to study the modes of interaction and characteristics of the (geographical and organized) proximity relations between dairy farmers in two villages with contrasting traits, located in the State of Pará, in the Brazilian Amazon. In doing so, we have sought to highlight their practices and to analyse the formation and dissemination of practices and techniques at the local level.

Our research has enabled us to bring to light the coexistence of very different socio-technical production models followed by distinct groups of farmers, respectively called smallholders or specialized family farmers and corporate farmers. Communication and exchanges between these different types of farmers structure the local production system and make milk production possible. However, networks are fragile and the sustainability of the activity depends heavily on the role played by certain intermediaries who serve as gatekeepers and facilitate the dissemination of information and techniques (medium or low tech innovations) between different local groups and actors while ensuring the supply of inputs and the sale of certain products.

Relations of geographical proximity facilitate the dissemination of these techniques, particularly through exchanges between actors in the villages (especially in Nova Jerusalem, which is more isolated), but also through some producers' occasional trips to the city. Organized proximity relations help cement the local ties and facilitate the implementation of joint actions: however, these joint actions are often undertaken by farmers who belong to the same category of producers, or to the same religious community, which is indicative of the important role played by the logic of similarity. The cooperative in Nova Jerusalem and (to a lesser extent) Mandacaru villagers' association alone have been able to foster collaborative relations, and therefore organized proximity (based on a logic of belonging) between producers of different categories, which has enabled the latter to work together, though limitedly so. These actions are related to the setting and diffusion of organizational innovations.

These proximity relations appear to play a great role in the territorial development of the observed areas, and especially participate in their sustainable dimensions. First, it appears that the local level is crucial and that the existence of geographical proximities is at the core of the possibility to discuss, to exchange and to diffuse techniques and practices locally. But organized proximity relations play the key role, be they based on the logics of belonging or similarity. They enable producers who belong to various networks to interact and to exchange, in a way to maintain the local agreement on development processes, despite different technological and innovative choices. This result suggests that the lack of interaction between different groups at local level could impede the possibilities of territorial development. Local policies must promote local gatekeepers and animation of new arrangements, who take advantage of various organized proximities in order to improve the coherence of virtuous systems in terms of eco-efficiency, to link diverse productive models, groups of producers and people, and allow the coexistence of different models of innovation.

Finally, it should be noted that the power relations within the interaction networks are strong and often respond to short-term interests. Thus, the specialized farmers are able, through their central position in the networks, to provide certain paid-for services and to sell or buy animals in ways that enable them to earn significant margins at the expense of smallholders. Yet, the sustainability of the milk production pools depends on maintaining and developing the small farmers' production, which, among other things, requires that the sale of calves be reduced during the dry

season. It would, therefore, be in the specialized producers' own interest to contribute to consolidating the production systems of smallholders and to limit their immediate profits. This change in posture, from dominance to mediation or facilitation, seems to be a prerequisite to the development of eco-efficient agrarian systems, beyond the occasional innovative practices developed by some specialized producers. New arrangement through strengthening of collective transformation tools for example could facilitate this process.

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REFERENCES

Akrich, M., Callon, M., Latour, M., & Monaghan, A. (2002). The key to success in innovation part i: The art of interessement. *International Journal of Innovation Management*, *6*(2), 187–206.

Andrew, C., Klein, J.-L., & Mohamoud, H. (2010). *Social Innovation: What is it and why is it important to understand it better*. Montréal: CRISES.

Compagnone, C., & Hellec, F. (2015). Farmers' professional dialogue networks and dynamics of change: The case of ICP and no-tillage adoption in Burgundy (France). *Rural Sociology*, *80*(2), 248–273.

de Assis Costa, F. (2005). Questão agrária e macropolíticas para a Amazônia. *Estudos Avançados*, *19*, 131–156.

Falk, I., & Harrison, L. (1998). Community learning and social capital: "Just having a little chat". *Journal of Vocational Education & Training*, *50*(4), 609–627.

FAO (2014). *The state of Food and Agriculture. Innovation in family farming*. Rome: FAO.

Favareto, A. (2016). Beyond 'family farming versus agribusiness' dualism: Unpacking the complexity of Brazil's agricultural model. Future Agricultures Working Paper 138. Retrieved from https://opendocs.ids.ac.uk/opendocs/handle/123456789/12717

Fearnside, P. M. (2001). Soybean cultivation as a threat to the environment in Brazil. *Environmental Conservation*, *28*, 23–38.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*, 897–920.

Grossetti, M., Barthe, J. F., & Chauvac, N. (2011). Studying relational chains from narrative material. *Bulletin of Sociological Methodology*, *110*(1), 11–25.

Handcock, M. S., Hunter, D. R., Butts, C. T., Goodreau, S. M., & Morris, M. (2008). Statnet: Software tools for the representation, visualization, analysis and simulation of network data. *Journal of Statistical Software*, *24*(1), 1548–7660.

Hervieu, B., & Purseigle, F. (2015). The sociology of agricultural worlds: From a sociology of change to a sociology of coexistence. *Review of Agricultural and Environmental Studies*, *96*, 59–90.

Hirsch-Kreinsen, H. (2018). "Low-tech" innovations. *industry and innovation*, *15*(1), 19–43.

Hubert, L., & Schultz, J. (1976). Quadratic assignment as a general data analysis strategy. *British Journal of Mathematical and Statistical Psychology*, *29*(2), 190–241.

IBGE—Brazilian Institute for Geography and Statistic. (2010). *Censo, sistema agregador de informações do IBGE sobre os municípios e estados do Brasil*. Retrieved from https://cidades.ibge.gov.br/brasil/pa/paragominas/panorama

Lazega, E. (2001). *The collegial phenomenon: The social mechanisms of cooperation among peers in a corporate law partnership*. Oxford: Oxford University Press.

Loreto, V., Servedio, V. D. P., Strogatz, S. H., & Tria, F. (2017). Dynamics on expanding spaces: Modeling the emergence of novelties. In M. Degli Esposti, E. G. Altmann, & F. Pachet (Eds.), *Creativity and universality in language*. Cham, Switzerland: Springer Verlag.

McIntyre, B. D., Herren, H. R., Wakhungu, J., & Watson, R. T. (2009). *International assessment of agricultural knowledge, science and technology for development: Global report*. Retrieved from https://www.globalagriculture.org/fileadmin/files/weltagrarbericht/IAASTDBerichte/GlobalReport.pdf

Pacheco, P., & Poccard-Chapuis, R. (2012). The complex evolution of cattle ranching development amid market integration and policy shifts in the Brazilian Amazon. *Annals of the Association of American Geographers*, *102*(6), 1366–1390.

Pierri, F. M. (2013). How Brazil's agrarian dynamics shape development cooperation in Africa. *IDS Bulletin*, *44*, 69–79.

Piketty, M.-G., Poccard-Chapuis, R., Drigo, I., Coudel, E., Plassin, S., Laurent, F., & Thâles, M. (2015). Multi-level governance of land use changes in the Brazilian Amazon: Lessons from Paragominas, State of Pará. *Forests*, *6*, 1516–1536.

Polge, E., & Torre, A. (2017). Territorial governance and multiple proximity. The case of public policy arrangements in Amazonia. *Papers in regional science*. https://doi.org/10.1111/pirs.12308

Sáenz, J., Aramburu, N., & Rivera, O. (2009). Knowledge sharing and innovation performance: A comparison between high-tech and low-tech companies. *Journal of Intellectual Capital*, *10*(1), 22–36.

Torre, A., & Rallet, A. (2005). Proximity and localization. *Regional Studies*, *39*, 47–59.

Torre, A., & Wallet, F. (2016). *Regional development in rural areas. Analytical tools and public policies*. *Springer Briefs in Regional Science*. New York: Springer.

van der Ploeg, J. D., Ye, J., & Schneider, S. (2015). Rural development: Actors and practices. In P. Milone, F. Ventura, & J. Ye (Eds.), *Constructing a new framework for rural development* (pp. 17–30). Bingley: Emerald Group Publishing.

Westley, F., & McConnel, J. W. (2017). *The evolution of social innovation. Building resilience through transitions*. Cheltenham: Edward Elgar.

Westley, F., & McGowan, K. (2017). *The evolution of social innovation*. Cheltenham: Edward Elgar Publishing.

Wilson, G. A. (2007). *Multi-functional agriculture: A transitional perspective*. Wallingford: CABI International.

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