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SPATIAL PATTERNS OF COCOA-BASED AGROFORESTRY FIELDS IN TOMÉ-AÇU, NORTHEAST PARÁ, BRAZIL

ABSTRACT: The growing need for information on the dynamics of land use and agricultural activity in the Amazon requires additional studies. This research work aimed to propose a methodology for mapping small-scale cocoa fields, as well as discussing the spatial dynamics of these fields in the municipality of Tomé-Açu, state of Pará. A database was built on the QGIS platform, intended for manipulation and analysis of georeferenced data. The mapping of cocoa fields comprised a 2017, 3 m spatial resolution PlanetScope image mosaic, bands 1, 2 and 3. Images were classified by preliminary visual analysis of spatial and spectral patterns. The product was further refined through participatory mapping with local stakeholders. Cocoa fields predominated in landholdings smaller than 50 ha, which is the size of the fiscal module defined for the study area. Nearly 4,000 hectares of cocoa fields were registered in 2017. These fields are clustered near the road network, in consolidated agricultural areas, far from the agricultural expansion frontier.

KEYWORDS: Geotechnologies, Spatial analysis, Perennial crops.

PADRÕES ESPACIAIS DE SISTEMAS AGROFLORESTAIS COM CULTIVO DE CACAU EM TOMÉ-AÇU, NORDESTE PARAENSE

RESUMO: A crescente demanda por informações sobre a dinâmica de uso das terras e da atividade agrícola na Amazônia, exige um esforço para que novos estudos sejam realizados. Este trabalho teve por objetivo propor uma metodologia para o mapeamento de pequenos cultivos de cacau, bem como discutir as relações espaciais dos mesmos no contexto do município de Tomé-Açu, Estado do Pará. Para isso, foi construída uma

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base de dados na plataforma QGIS, destinada à manipulação e à análise de dados georreferenciados. O mapeamento dos cultivos de cacau considerou mosaico de imagens PlanetScope, bandas 1, 2 e 3, ano de 2017, com resolução espacial de 3 m. As imagens foram classificadas por análise visual preliminar, considerando padrões espaciais e espectrais. O produto obtido foi refinado posteriormente a partir de mapeamentos participativos com atores locais. Verificou-se que as áreas com cacau se concentram em propriedades de até 50 ha, valor este relativo ao módulo fiscal definido para a área de estudo. Foram registrados quase 4 mil hectares de cultivos de cacau no ano de 2017. Os plantios de cacau estão concentrados próximos à malha viária, em áreas agrícolas consolidadas, distantes das frentes pioneiras de expansão agrícola.

PALAVRAS-CHAVE: Geotecnologias, Análise espacial, Cultura perene.

PATRONES ESPACIALES DE SISTEMAS AGROFORESTALES CON CULTIVO DE CACAO EN TOMÉ-AÇU, NORDESTE DE LA AMAZONÍA BRASILEÑA

RESUMEN: La creciente demanda de información sobre la dinámica del uso del suelo y la actividad agrícola en la Amazonía requiere un esfuerzo para la realización de nuevos estudios. Este trabajo tuvo como objetivo proponer una metodología para el mapeo de pequeños cultivos de cacao, así como discutir sus relaciones espaciales en el contexto del municipio de Tomé-Açu, Estado de Pará, Brasil. Para ello, se construyó una base de datos en la plataforma QGIS, destinada a la manipulación y análisis de datos georreferenciados. El mapeo de cultivos de cacao consideró mosaico de imágenes PlanetScope, bandas 1, 2 y 3, año 2017, con una resolución espacial de 3 m. Las imágenes se clasificaron mediante un análisis visual preliminar, considerando patrones espaciales y espectrales. El producto obtenido se refinó aún más a partir del mapeo participativo con actores locales. Se encontró que las áreas con cacao se concentran en propiedades de hasta 50 ha, lo cual está relacionado con el módulo fiscal definido para el área de estudio. En 2017 se registraron casi 4.000 hectáreas de cultivos de cacao. Las plantaciones de cacao se concentran cerca de la red vial, en áreas agrícolas consolidadas, lejos de los frentes pioneros de expansión agrícola.

PALABRAS CLAVES: Geotecnologías, Análisis espacial, Cultura perenne.

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is one of the most historically documented pre-Columbian cultures, and its multiple uses were already recorded by Europeans in the early 16th century. However, Zarrillo et al. (2018), claim that the cocoa domestication process began before the so far accepted theory, until then attributed to Mesoamerican peoples.

Brazil is the sixth largest cocoa producer in the world after Côte d'Ivoire, Ghana, Indonesia, Nigeria and Cameroon (FAO, 2018). The state of Pará is the largest cocoa producer in Brazil with 53.64% of the national production, with a production value of about $300 million dollars (IBGE, 2020). Thus, the importance of cocoa in the economic sustenance of small farms in several tropical countries is clear (LÄDERACH et al., 2013).

In the context of spatial analysis of agricultural areas, thematic classifications in traditional approaches usually do not produce as much information as one could obtain using experienced photointerpreters. Such restrictions occur because, in general, ground targets are characterized by a wide spectral variability, local textural patterns and a complex matrix of environments that prevents analyses that are more reliable and interpretations of ground targets from being made.

In the Amazon, the mapping of agricultural areas is often limited by the small average size of most cultivated areas, as well as by the use of agricultural practices/management, such as shading and intercropping, which add spurious signs to the crop of interest in the analysis. Thus, according to Watrin, Gerhard and Maciel (2009), commonly used medium-resolution spatial/spectral images, such as those in the Landsat series, present serious restrictions for the detection of these small agricultural areas in the Amazon.

In the detection of annual crops in the Amazon, the period referring to the available images from optical sensors constitutes a considerable aggravating factor. Watrin et al. (2020) point out

that, as the lowest cloud cover rates are associated with the second half of the year, annual crops, according to the traditional agricultural calendar of the region, will not be mapped, as they will be in the phase of crop residues, or even being converted to the initial stage of secondary succession.

On the other hand, perennial crops (long crop cycles), suffer great influence from the area where they are circumscribed, and can be confused spectrally many times with the forest environment of their surroundings during the development phase of the crop. In the case of cocoa crop, mainly in the state of Pará, Mendes (2018) remarks that this behavior is enhanced, due to the fact that cocoa cultivation usually consists of an Agroforestry System (SAF).

Therefore, based on the demands for obtaining information related to the role of the dynamics of agricultural activity in the Amazon, this research work aims to propose a methodological approach for mapping small areas of cocoa cultivation. Also, we aim to discuss the spatial relations of these crops in the context of the landscape of the municipality of Tomé-Açu, in the Northeast Brazilian Amazon. This mapping represents a portion of the contribution to update, with the greatest possible accuracy, the data and strategic information on the quantitative and spatial location of cocoa-producing areas in the State of Pará, in compliance with the goals of the 2011-2019 PROCACAU State Program and, therefore, in support of the local Sector Public Policies.

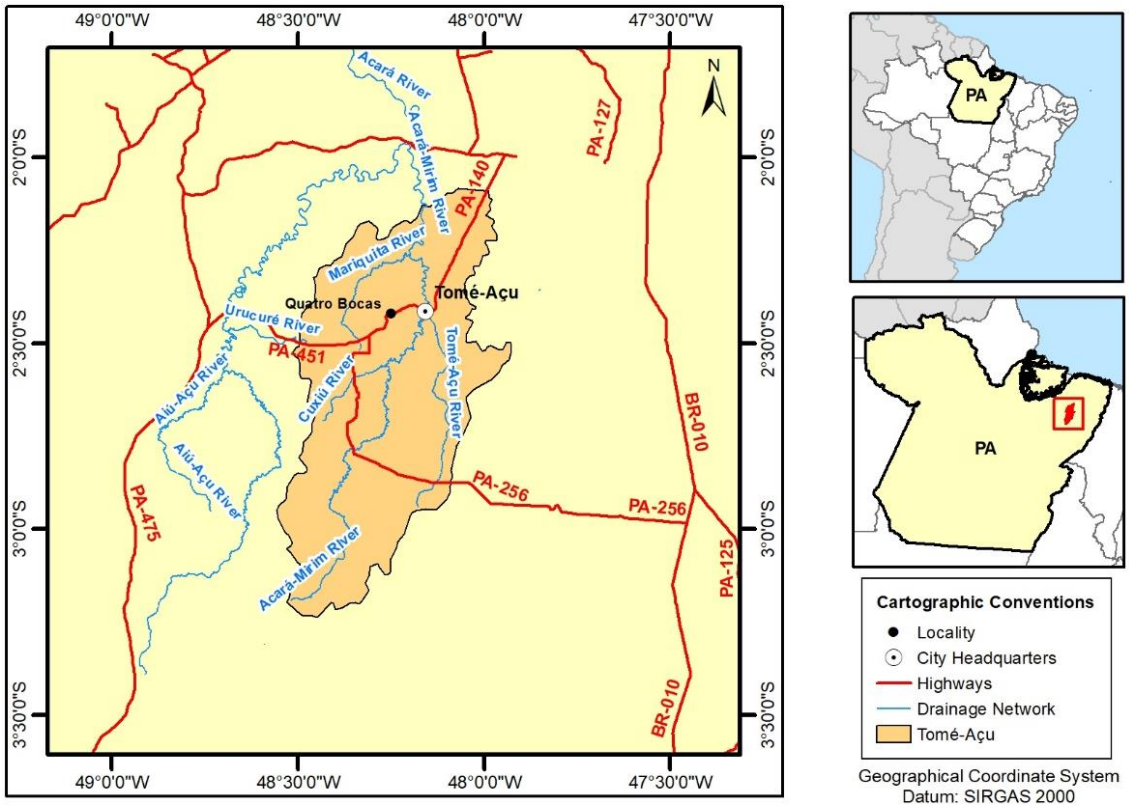
MATERIAL AND METHODS

STUDY AREA

The study area corresponds to the municipality of Tomé-Açu, located in the Northeast of the state of Pará (Figure 1), between the geographic coordinates of the latitudes 02°04°46,67" S and 03°14'30,92" S and of the longitudes 47°55'18,52" W and 48°33'38,22" W. The municipality has a total area of 5,149.36 km² (IBGE, 2019), and the road network is subordinate to the axis defined by highway PA-256,

that cuts through much of the municipality, in the East-West direction, and by a secondary stretch of the PA-451 highway. The drainage network is represented by the Acará-Mirim river basin and its tributaries, the most important being the Tomé-Açu River.

Figure 1. Location of the study area.



Source: Prepared by the authors.

The climate according to the Köppen classification is of the Awi type, defined as rainy tropical with a clear dry season, varying from three to four months, with less than 60 mm of monthly rain. Monthly average temperatures range from 27.5°C to 28.4°C, with an annual monthly average of 27.9°C. The average annual precipitation ranges from 2,144 mm to 2,581 mm, with a period of abundant rainfall from December to May, in opposition to the dry period from June to November. The relative humidity of the air ranges from 82% to 88% (RODRIGUES et al., 2001).

The dominant soils in the study area are the typical dystrophic Yellow Latosols and the typical dystrophic Yellow Acrisols, in flat or smooth wavy relief. They constitute groups of deep mineral soils, well drained, poorly structured, with low level of natural chemical fertility. In a lesser representation, the typical dystrophic Haplic Gleysols, the typical dystrophic Red-Yellow Latosol and the typical dystrophic Fluvisols (RODRIGUES et al., 2001) soils are also present.

PHYTOTECHNICAL AND SPECTRAL ASPECTS OF COCOA CROP

Agroforestry systems (SAFs) have various forms of land use, where trees and shrubs are associated with agricultural crops, pastures and/or animals (RIBASKI; MONTOYA; RODIGHERI, 2001). Among the most widespread SAFs in the world is cocoa, a perennial cycle crop developed often under shading in systematized management (LANDAU; SILVA, MOURA, 2020), simulating the natural environmental conditions required by the species.

The desired shading in the cocoa crop can also be realized from the selection of individual tree in forest areas, which will make the upper extract of the canopy. Thus, the vertical structure in the phase of full development of cultivation becomes complex by the formation of several strata and by the height of the canopy. These characteristics allow for the formation of internal shading for the crop and its perception by remote sensors, very similar to that defined by typic targets of forest typology, and this agricultural target can be treated as a "complex canopy".

An aspect still to be considered for the municipality of Tomé-Açu is related to the fact that, according to data from the National Institute of Colonization and Agrarian Reform (INCRA, 2013), cocoa crops are associated with a region, in the State of Pará, where the fiscal module of rural property is 50 ha, a characteristic that significantly impacts land use.

MANIPULATION AND ANALYSIS OF SPATIAL DATA

The construction of the spatial database of this mapping on the QGIS platform was based on the cartographic database of the Brazilian Institute of Geography and Statistics (IBGE) of 2017, using the road network, drainage network, municipality boundary and population centers. In addition, the boundaries of rural properties were aggregated in this database, based on the National System of Rural Environmental Registry (SICAR), regulated through Decree No. 7,830 of October 17, 2012, integrating the CAR of all Federation Units (BRASIL, 2012).

Due to the limitations for the mapping of the systematized plantations of the cocoa crop, we sought an orbital product with a spatial and spectral resolution thinner than the traditional images for mapping the use and cover of the land. Thus, we opted for the use of products of the PlanetScope satellite (SCCON, 2019), with 3 m spatial resolution, made available by the Secretary of State for Environment and Sustainability of Pará (SEMAS/PA), in mosaic of images in "geotiff" format, colored composition RGB 3/2/1.

The choice of images was from the year 2017, being the most recent available during the conduction of this research, besides presenting lower rates of cloud cover and shadows. Planet images were not submitted to pre-processing treatments, considering that the method defined in this research work for delimitation of polygons of cocoa plantations is based on visual interpretation of data

The selected images were classified considering a phase of preliminary visual interpretation of the features associated with cocoa plantations, from spectral (tonal and texture) and spatial (plots, streets and geometry) attributes, with the support of the land grid defined in the municipal CAR. The polygons associated with the features of interest were delimited from vector editing tools of the QGIS platform, taking into account to obtain the

preliminary thematic product, only two classes (cocoa and remaining classes).

After this thematic product, a participatory mapping was conducted with rural producers and technicians from contributing local agricultural institutions (Municipal Secretary for the Agriculture - SEMAGRI; Mixed Agricultural Cooperative of Tomé-Açu-CAMTA; Company of Technical Assistance and Rural Extension of the State of Pará - EMATER Pará and; Executive Committee of the Cocoa Farming Plan (CEPLAC).

The participatory mapping consisted of work meetings, with the active presence of local producers and technicians, in order for these social actors to evaluate and contribute to the refinement of the preliminary thematic product generated in the laboratory, considering their experiences and knowledge (IFAD, 2009).

In the performed participatory mapping, properties with cocoa cultivation for field visitation were also selected, through a random distribution. During the visits to the selected areas, location points were taken with the help of GPS navigation gadgets, which were later incorporated into the database, as terrestrial truth.

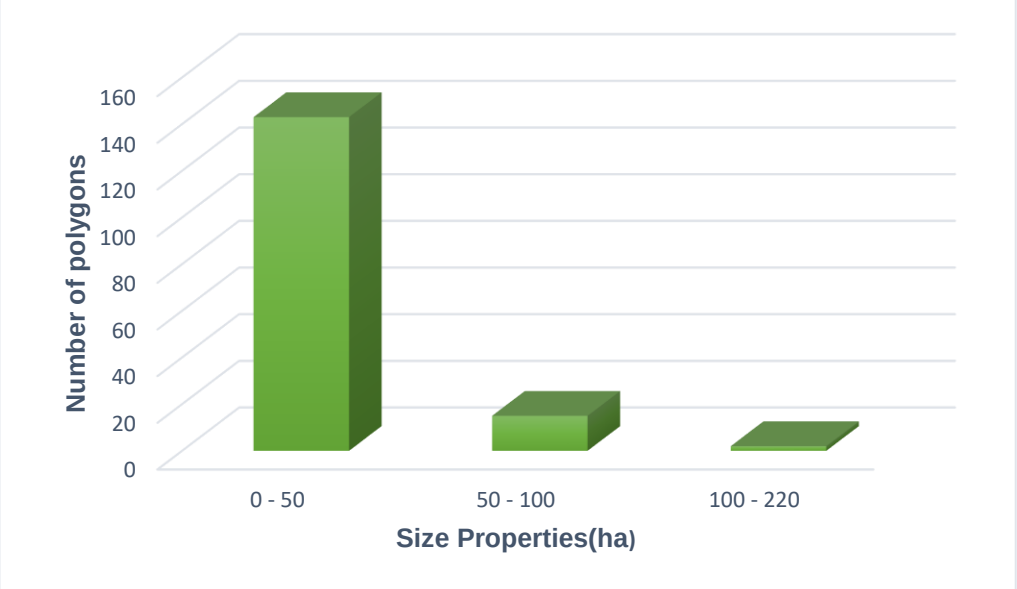
The stage of integration of laboratory and field data took into consideration, besides the polygons already mapped from the visual interpretation of the images, the data obtained in the different surveys carried out in the field with the local actors. With the convergence of these data, the reclassification of the images was conducted, and at this occasion, they were submitted to editing aimed at generating the final thematic image. From the obtained product, the area of focal interest was quantified in this research work (cocoa) for the year 2017. Based on the spatial distribution of polygons associated with the occurrences of cocoa in the study area, spatial analyses were performed to verify the sectors of higher concentration of this crop, as well as to evaluate the relationship of occurrences with the size of the

property and the proximity of the existing road network.

RESULTS AND DISCUSSION

According to Figure 2, it was possible to observe that cocoa plantations in the municipality of Tomé-Açu are concentrated in an area that corresponds to a fiscal module, that is, 50 ha. Thus, this spatial distribution pattern indicates that in the study area there is a predominance of cocoa plantations in small farms, corresponding to 99.37% of the total. It is noteworthy that, according to Law No. 8,629/1993 (BRASIL, 1993), a small property is considered all those land holdings up to four fiscal modules, in size. This pattern of behavior was also observed by Sousa et al. (2019) in rural properties in the Region of Mesoamerica, where cocoa crops are mainly associated with the small producer. In this way, the proposition of Läderach et al is confirmed, (2013) in reference to the socioeconomic importance of cocoa in the family income of small producers in several tropical countries.

Figure 2. Relationship between the size of the property and the number of polygons mapped as cocoa plantations in the municipality of Tomé-Açu, PA.

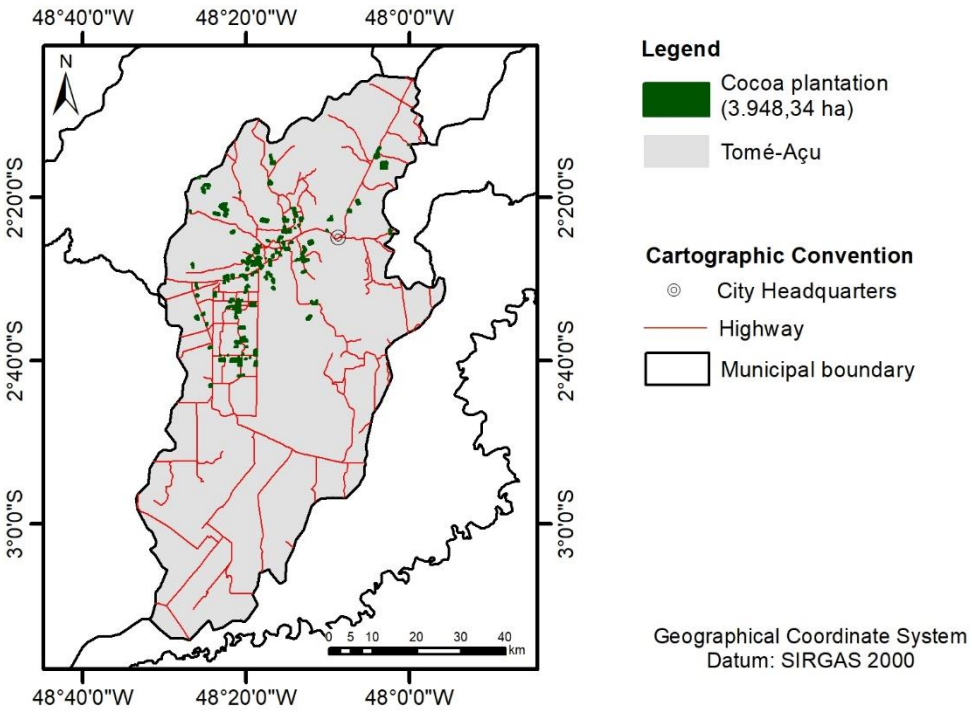


Source: Field and lab data.

In another spatial analysis, it was possible to quantify the cocoa planting areas present in the study area for the year 2017. According to Figure 3, 3,948.34 ha of areas cultivated with cocoa were recorded, with heterogeneous distribution, although concentrated in the North-Central part of the municipality. Comparing these data to those defined by the IBGE for the areas intended for cocoa harvest in this same year of study, 3,570 ha were recorded (IBGE, 2017). Thus, the areas mapped in this study represented 110.6% compared to IBGE data.

In view of the above, it is perceived from the mapping sources considered in this analysis, a possible tendency of increase in the areas intended to the harvest of cocoa crop. This finding was confirmed when consulting IBGE data for the year 2019, which recorded an increase in the area intended for cocoa harvest of 5.6% (200 ha) compared to that observed in 2017.

Figure 3. Spatial distribution of cocoa plantations in the municipality of Tomé-Açu, PA.



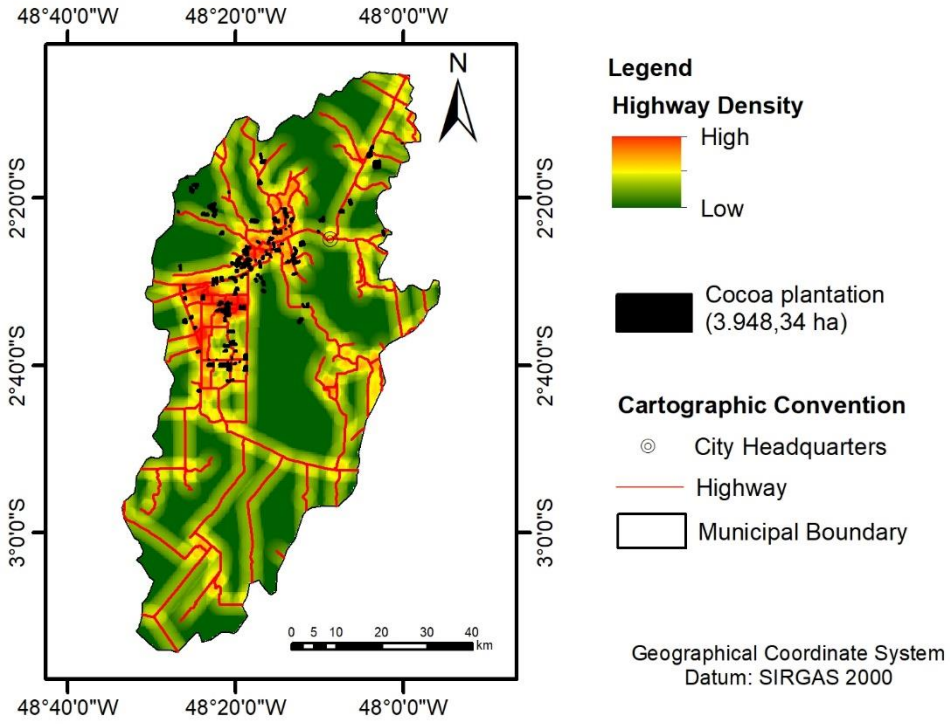
Source: Field and laboratory Data.

The data presented for the areas cultivated with cocoa are relevant, considering that, according to Coutinho et al. (2013), there are several interests of the demands for the generation of information related to the dynamics of agricultural activity in the world. The promotion of annual estimates of harvests and their relationship with the pricing of future markets, the measurement of environmental impacts and the formulation of public policies for agribusiness are just a few examples of the activities interested in the generated data about crops in the field.

In addition, in the context of the analyses that was carried out, another aspect that was considered refers to the influence of road infrastructure for the concentration of cocoa plantations (Figure 4). Given that such a situation is essential for the flow of production, as well as, for the incoming of agricultural supplies, this prerogative, in the present case, was positive. Figure 4 shows that the areas with the highest concentration of cocoa plantations are associated with the sectors of the municipality where the highest density of the road network occurs.

According to Mendes (2018), cocoa yield in the state of Pará, of approximately 900 kg/ha, is considered relatively big, when compared, for example, to the state of Bahia (300 kg/ha), or even to the major world producers Ivory Coast (660 kg/ha) and Ghana (550 kg/ha). However, this high productivity value hides the high pedogical diversity of the state of Pará, which has producing regions in soils of high natural fertility (Latosol Roxo), in the Transamazon region, which can reach up to 2,000 kg/ha. On the other hand, there are producing regions with soils of low natural fertility (Yellow Latosol and Yellow Argisol), as observed in the case of the municipality of Tomé-Açu, which can only achieve satisfactory levels of productivity through chemical and/or organic fertilization.

Figure 4. Spatial distribution of cocoa plantations associated with the density of the road network in the municipality of Tomé-Açu, PA.



Source: Field and laboratory dados.

Therefore, we see the importance of a consolidated road network to facilitate inputs transportation, since it is necessary to fertilize the soil to meet the nutritional demands of cocoa (SCHROTH et al., 2016). Moreover, with easier access to the producing areas, freight tends to become cheaper not only for inputs transportation, but also for the outflow of production.

Still considering Figure 4, it can be observed that the mapped cocoa producing areas tend to focus on the sectors of the municipality with more consolidated landscape, associated with the density of the road network, as previously seen. In addition, these sectors are close to the two main population centers of the municipality, Tomé-Açu and Quatro-Bocas, in the domain of the oldest colonization area,

started by Japanese immigrants, since 1929. The participatory mapping showed strong evidence that the new cocoa production areas in the municipality continue to expand considering regions with more consolidated agricultural landscape.

CONCLUSIONS

The methodological approach employed, based on the integration of orbital images of high spatial resolution and data from participatory surveys with local actors, proved effective for mapping small cocoa crops in the study area. The information generated is of great relevance in the context of the creation of public policies for agribusiness at the municipal and state levels.

It was found that cocoa plantations in the study area are mostly developed in small rural areas of up to 50 ha, a size corresponding to the limit of the fiscal module defined for the municipality of Tomé-Açu.

Almost 4,000 hectares of cocoa crops were recorded in 2017, and the field surveys carried out detected a certain trend of growth of these areas after the year of analysis.

A close relationship was observed between the concentration of cocoa crops and the presence of the existing road network, indicating dependence of the crop on the infrastructure, given the demands for agricultural supplies. The distribution of cocoa crops tends to focus on the North-Central part of the study area, in more consolidated agricultural landscape sectors, thus not being associated with the pioneering fronts of agricultural expansion.

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