

Mapping three permanent crops and evaluation of rural property patterns in São Miguel do Guamá, Pará, Brazil

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ABSTRACT

The objective of this study was to map three permanent crops (citrus, palm oil, and black pepper) in São Miguel do Guamá, Pará State, Brazil, and characterize their rural property profiles. Characterization was performed by visual interpretation of Maxar images of <1 m spatial resolution from Google Earth and overlaying them with the Cadastro Ambiental Rural (CAR), the Brazilian rural environmental register. We grouped the rural properties by size class according to the municipal fiscal module (FM), which is 55 ha. Private properties were classified as follows: small, up to 1 FM; medium, from 1 to 5 FM; and large, properties larger than 5 MF. The 2211 ha mapped region showed that palm oil (72%, 1595 ha) was predominant, followed by black pepper (14%, 317 ha), and citrus (14%, 298 ha). Citrus and black pepper were predominant in the small and medium properties, whereas palm oil was predominant in the large properties. According to environmental laws, most rural properties (76%) had environmental liabilities in permanent environmental preservation areas (Áreas de Preservação Permanente–APP). A fraction of plated area of Citrus (28%) and black pepper (31%) were in properties without CAR. Only palm oil cultivations were 100% in properties registered in the CAR system. These results help to better understand the spatial distribution of the mapped agricultural crops in the study area, the dimensioning of the local and regional economy and environment, and the development of public policies to assist family agriculture farmers in the region in accessing rural credits.

Index terms: Citrus, black pepper, palm oil, permanent crops, rural environmental register, supervised classification.

Ideias centrais

- Analisou-se a presença e ausência do registro no Cadastro Ambiental Rural, considerando o tamanho das propriedades rurais e o tipo de cultura.
- O mapeamento das culturas permanentes nas propriedades rurais foi realizado utilizando a interpretação visual por imagens de satélites de alta resolução do Google Earth.
- Obteve-se uma melhor compreensão da distribuição espacial e do perfil dos estabelecimentos produtores de culturas permanentes de citros, dendê e pimenta-do-reino na região.
- Identificou-se a necessidade de diminuir os passivos ambientais de Área de Preservação Permanente nas propriedades rurais analisadas.
- Constatou-se maior presença de pequenos produtores nas culturas permanentes.

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Mapeamento de três culturas permanentes e avaliação dos padrões de propriedades rurais em São Miguel do Guamá, Pará, Brasil

O objetivo deste estudo foi mapear três culturas permanentes (citros, dendzeiro e pimenta-do-reino), em São Miguel do Guamá, no estado do Pará, e caracterizar o perfil de suas propriedades rurais. A caracterização foi feita por meio de interpretação visual de imagens Maxar com resolução espacial <1 m pelo Google Earth, sobrepostas com o Cadastro Ambiental Rural (CAR). Agrupamos as propriedades rurais, por tamanho, pelo módulo fiscal (MF) municipal, que é de 55 ha. As propriedades foram classificadas conforme a seguir: pequenas propriedades, até 1 MF; médias, de 1 a 5 MF; e grandes, propriedades maiores que 5 MF. A região com 2211 ha mapeados mostrou predomínio do dendê (72%, 1595 ha), seguido da pimenta-do-reino (14%, 317 ha) e citros (14%, 298 ha). As culturas de citros e pimenta-do-reino predominaram nas pequenas e médias propriedades, e o dendê, nas grandes propriedades. Pela legislação ambiental, a maioria das propriedades rurais (76%) apresentou passivo ambiental em áreas de preservação permanente (APP). Citros (28%) e pimenta-do-reino (31%) estão em propriedades rurais sem CAR. Apenas as culturas de dendê estavam em propriedades com CAR. Estes resultados contribuem para a melhor compreensão da distribuição espacial das culturas agrícolas mapeadas na área de estudo, no dimensionamento da economia e do meio ambiente local e regional e no desenvolvimento de políticas públicas de acesso ao crédito rural principalmente aos agricultores familiares da região.

Termo de indexação: citros, pimenta-do-reino, dendê, culturas permanentes, cadastro ambiental rural, classificação supervisionada.

INTRODUCTION

The growing global demand for agricultural commodities has driven the expansion and intensification of agriculture in tropical countries (Foley et al., 2005). Thus, there has been a strong expansion of these agricultural areas over natural areas, causing habitat reduction and fragmentation of the native vegetation (Lambin et al., 2003). Therefore, it is strategic to map and know the profile of rural properties with the quantities of properties, size and percentage of the area, type of crops, and areas determined by law to be conserved, such as Permanent Preservation Areas (APP) and Legal Reserves (RL). This is important for the planning of the production sector and the development of public policies regarding their different issues.

The registration of APP and RL is embedded in the Rural Environmental Register (CAR) originating from the federal law (Lei nº 12.651, 25 May 2012) (Brasil, 2012), also known as the “Código Florestal” (“Forestal Law”). The CAR is mandatory for all rural properties to integrate environmental information from rural properties for control, monitoring, environmental and economic planning, and combating deforestation. APP and RL play an important environmental role because they are responsible for the maintenance, preservation, and conservation of ecosystems (Soares-Filho et al., 2014; Jung et al., 2017).

Land use mappings contribute to public policies and strategic planning in the productive sector. This can generate reports for elaboration of actions aimed at rural development, for instance, allowing access to rural credit related to family farming and improving the production chain of locally produced crops. Long-term land-use mapping can also contribute to the environmental regularization of the study area.

Despite the existence of some land-use mapping products in Brazil to assess land-use changes, there is still room to improve the capability of mapping perennial crops (Almeida et al., 2016; Machichi et al., 2023). MapBiomass (Souza Jr. et al., 2020; MapBiomass, 2023) and TerraClass (Almeida et al., 2016) are the best available products; however, they are not based on high-resolution images. Therefore, they are not yet capable of identifying the wide variety of annual and perennial crops in Brazil. The limitations include the underestimation of small cultivations and lower capability to correctly identify crops that are less than two years old or areas with intercropped cultivation. Land use mapping based on high-resolution images is promising for identifying different perennial crops and their spatial distributions (Machichi et al., 2023).

Mapping and monitoring agricultural production is relevant to the knowledge of farm profiles. The microregion of Guamá, in the Northeast Paraense Mesoregion, Pará state, Brazil, has been the focus of mapping and monitoring permanent crops (citrus, palm oil, and black pepper). The Guamá Microregion is composed of 13 municipalities and shows high-diversity agricultural practices with

numerous family farmers and traders, favoring intense economic activity in the region (Costa et al., 2017). The monitoring and mapping initiative began in the municipality of Capitão Poço (Silvério et al., 2022).

In the present study, we selected the municipality of São Miguel do Guamá because it is related to a smaller planted area, which allows mapping of the entire planted area by visual interpretation of the polygons. These characteristics are essential to reduce the possibility of interpretation errors. Additionally, this municipality is located on an older and consolidated agricultural frontier in Pará state, which allows for greater stability in land-use dynamics. Therefore, we can use São Miguel do Guamá as a follow-up to characterize the profile of rural properties in the Microregion of Guamá because of the crop cultivation activity in the municipality (IBGE, 2017, 2022). The objective of this study was to map three permanent crops (citrus, palm oil, and black pepper) in São Miguel do Guamá using high-resolution satellite images available on Google Earth to characterize the profile of rural properties.

MATERIALS AND METHODS

This study was carried out between June 2022 and February 2023 in the municipality of São Miguel do Guamá, Pará state, Brazil (at -1.63 and -47.48). The study area covers 109,456 ha and exhibits high-diversity agricultural practices with numerous family farmers and, to a lesser extent, large rural properties. The main agricultural crops in the municipality include *açaí* (acai) palm, banana, coconut, *urucum* (achiote), rice, beans, corn, oranges, palm oil, and black pepper (IBGE, 2021a, 2022; Sedap, 2022). Consequently, it is important to monitor its dynamics in addition to its economic and environmental implications. Notably, there are 3161 ha of water surface, 1396 km of rivers, and 37206 ha of forest formations in this municipality, which are essential for the maintenance of the local ecosystem (Figure 1) (FBDS, 2022).

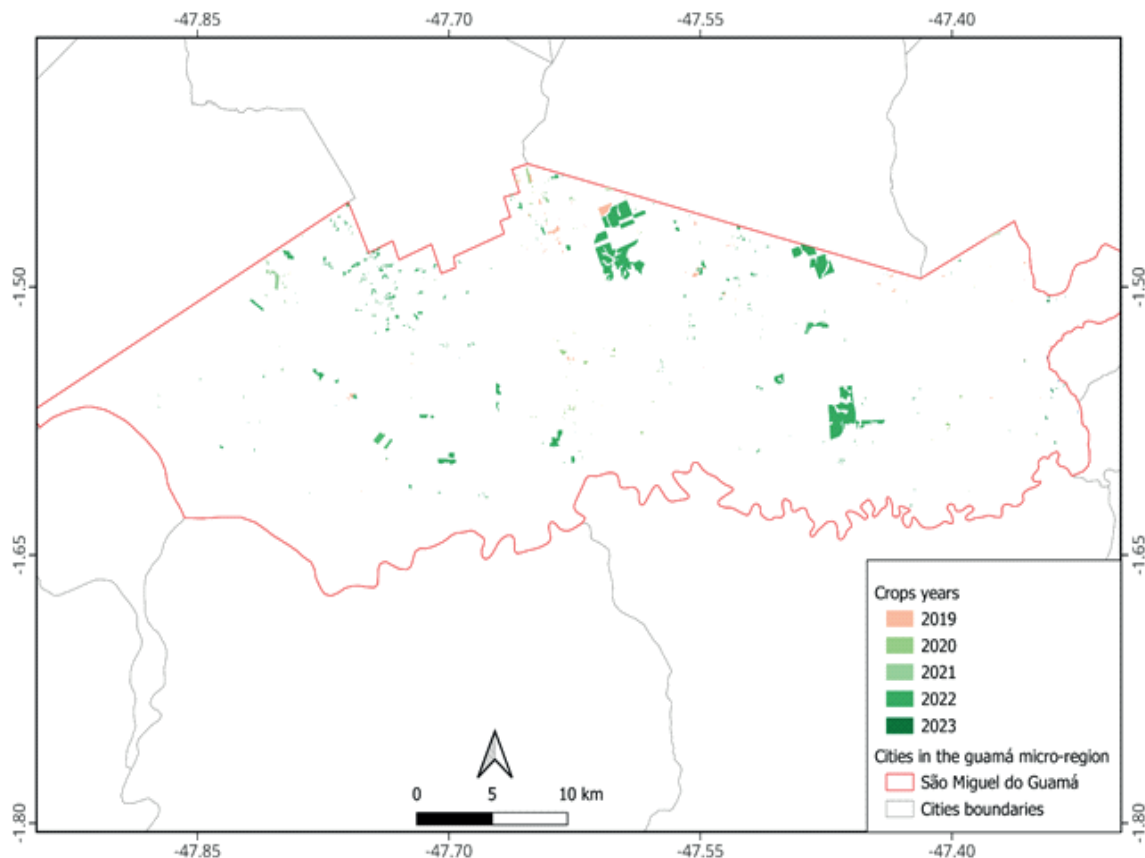


Figure 1. Distribution of crop years in the municipality of São Miguel do Guamá, Pará, Brazil.

To map the studied crops, we applied visual interpretations of RGB imagery from the Google Earth base map (captured by the Maxar Worldview 2 sensor) with a spatial resolution of 50 cm. We relied on visual interpretations of the images to map the areas occupied by the following permanent crops: citrus (species of the genus *Citrus*, Rutaceae), palm oil (palm trees of the genus *Elaeis*, Arecaceae), and black pepper (*Piper nigrum*, Piperaceae). These crops were selected because they represent some of the most recent great financial turnovers in the Brazilian market, and the images were available from 2019 to 2022 (Figure 2). Although there are other important permanent crops in the region, such as the acai palm, these images enable the discernment of these selected crop cover types and other relevant attributes through visual interpretation, such as canopy format and plant spacing. In addition, this methodology has been used as the basis for mapping and auxiliary data sources to train automated land-use classification and validation models (Zhang et al., 2020; Pan et al., 2021; Silvério et al., 2022; Passos et al., 2023).

Plant spacing was the main attribute used to separate the crop types, mainly citrus (6–7 × 4 m), black pepper (between 0.4 and 2.5 m), and palm oil (around 9 × 9 m); the latter was also due to the uniformity of the crowns (Duarte, 2004; Girardi et al., 2014; Gomes Junior et al., 2018). Maxar imagery allows the discrimination of these land cover types, disturbance events, and other relevant attributes through visual interpretation. This methodology has been used as the basis for various mapping and ancillary data sources to train automated land-use classification and validation models (Olofsson et al., 2014).

We also used data from Cadastro Ambiental Rural (CAR) to characterize the rural properties of citrus, palm oil, and black pepper in the study area. These data were downloaded in Abril 2023 from the registry system of CAR (SICAR)⁸. We defined three classes of rural properties according to the number of fiscal modules (FM): small property (FM < 1), medium property (1 ≤ FM ≤ 5), and large property (FM ≥ 5). The FM for São Miguel do Guamá is 55 ha (Brasil, 2012).

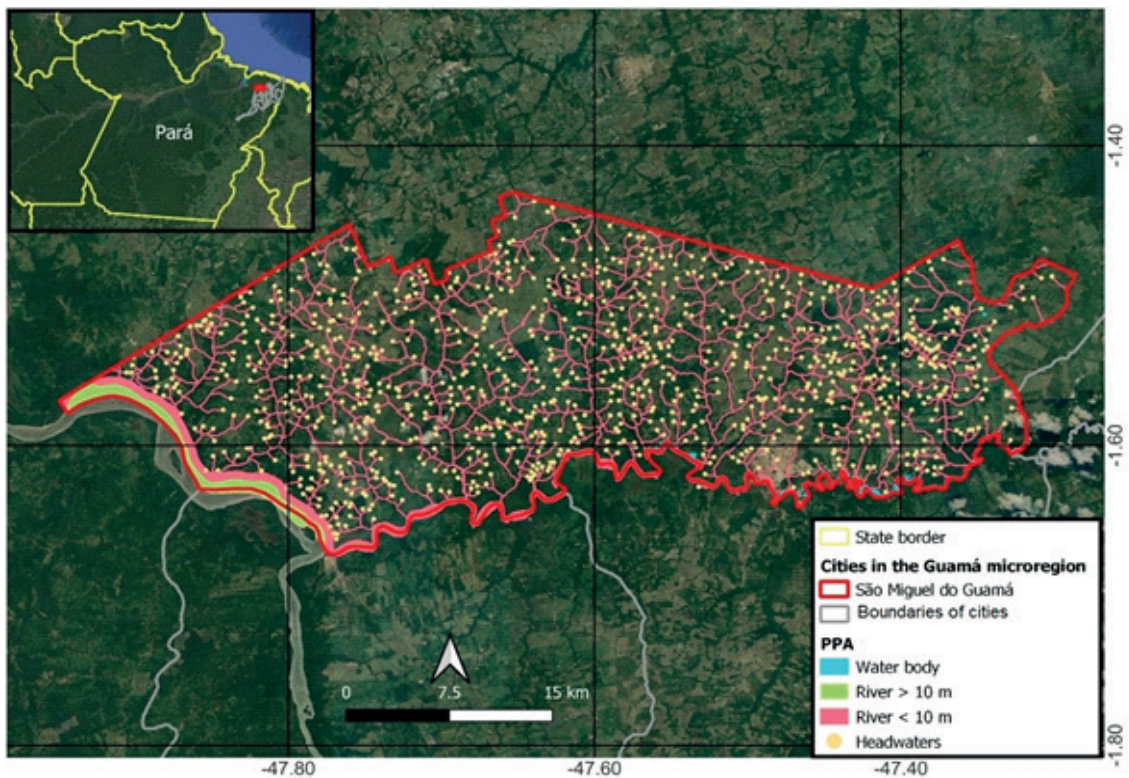


Figure 2. Permanent Preservation Areas (Áreas de Preservação Permanente - APPs), in the municipality of São Miguel do Guamá, Pará state, Brazil.

⁸ Available at: <<https://www.car.gov.br/#/>>.

For rural properties producing the three evaluated permanent crops, we quantified degraded areas of APP that need to be restored at the owner's expense, according to the Brazilian forest code. We used the anthropized area class of APP from the dataset of Fundação Brasileira para o Desenvolvimento Sustentável (FBDS, 2022). First, we calculated the intersection of the degraded APP with a subset of CAR for properties producing the selected crops. We then summarized the number of properties with degraded APP and the area occupied by permanent crops. We applied the functions available in the R statistical software package, version 3.4.4 (R Core Team, 2018).

RESULTS AND DISCUSSION

An area of 2211 ha was mapped for the three predominant crops in São Miguel do Guamá (Table 1). Of this total area, 298 ha corresponds to citrus, 1595 ha to palm oil, and 317 ha to black pepper. We identified 101 rural properties producing citrus, 118 producing black pepper, and 65 producing palm oil (Table 1). If we consider the number of farms in the different size classes, small farms show the highest black pepper production (77), followed by citrus (70) and palm oil (35) (Table 1). Based on the planted area and the most commonly used spacing for each crop, we estimated 124,208 citrus trees, 223,412 palm oil trees, and 198,375 black pepper trees (Figure 3).

Small- and medium-sized properties showed the largest production percentages – 64% (191.6 ha, 79,864.7 trees) for citrus, and 51% (160.5 ha, 100,377.75 trees) for black pepper. Large properties showed production of only 7.5% (22.3 ha, 9,315 trees) for citrus and 18.3% (58 ha, 36,302.63 trees) for black pepper. However, in large properties, palm oil had the highest production percentage (73%) (1,164.2 ha, 163,090.76 trees); consequently, 27% (431.6 ha, 60,321.24 trees) palm oil were in small and medium areas.

In Pará, these three crops represent 57% of the crop production and 33% of the harvested area (IBGE, 2021b). Edaphoclimatic conditions in the region favor the production of fruit crops, such as those reported here (Ribeiro et al., 2006; Alves et al., 2017). Furthermore, the type of spacing can delimit the type of farm and the property size. For instance, palm oil cultivation requires large plant spacing, occupying large planting areas (Mota et al., 2019) in properties defined here as large ($FM \geq 5$ ha). As a result, this characteristic may favor the diffusion of palm oil among large companies in the Amazon region, since this crop type is widely used in the production and trading of vegetable oil in the cosmetics, soap, and food industries (Homma, 2016).

However, unlike palm oil, more than half of area producing black pepper and citrus are in small ($FM > 5$) and medium ($1 \leq FM \leq 5$) properties in the municipality of São Miguel do Guamá. The smaller spacing may have facilitated the type of cultivation in these two property profiles, particularly

Table 1. Perennial crops mapped in the municipality of São Miguel do Guamá, Pará state, according to the size of rural properties in 2021. The sum of the planted area, grouped into small, medium, and large properties may be greater than the total area because of overlapping properties in the Cadastro Ambiental Rural (CAR).

Property size	Citrus		Palm oil		Black pepper	
	Number of properties	Area (ha) / percentage (%)	Number of properties	Area (ha) / percentage (%)	Number of properties	Area (ha) / percentage (%)
Small	70	99.3 (33.3%)	35	144.3 (9%)	77	85.7 (27%)
Medium	24	92.3 (31%)	18	287.3 (18%)	26	74.8 (23.6%)
Large	7	22.3 (7.5%)	12	1,164.2 (73%)	15	58 (18.3%)
Total with CAR	101	213.9 (71.8%)	65	1,595.8 (100%)	118	218.5 (68.9%)
Total without CAR ⁽¹⁾	-	84.2 (28.2%)	-	0.0 (0%)	-	98.9 (31.1%)
Total	101	298.1 (100%)	65	1,595.8 (100%)	118	317.4 (100%)

⁽¹⁾Total crop area excluding overlapping properties registered in the Cadastro Ambiental Rural (CAR).

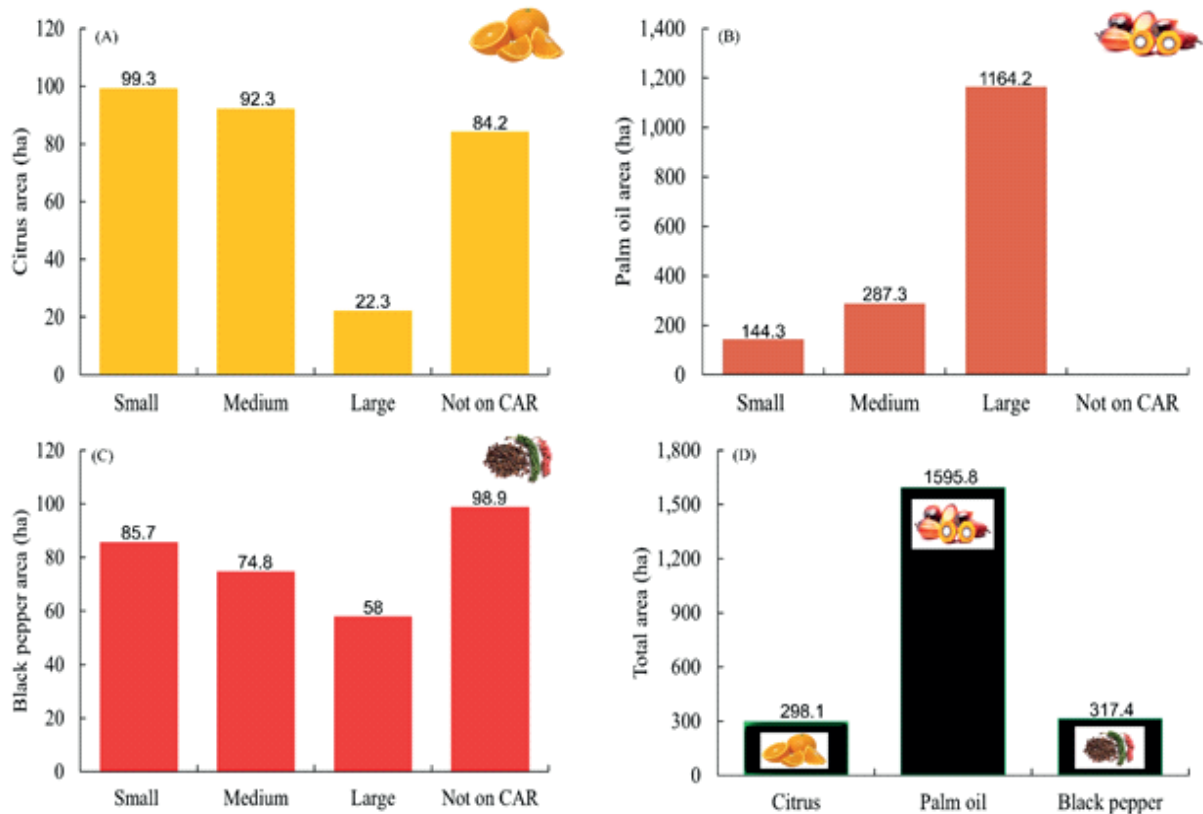


Figure 3. Cultivated areas according to the size of rural properties, occupied by the following crops: A, citrus; B, palm oil; and C, black pepper. D, total area. Municipality of São Miguel do Guamá, Pará state, Brazil.

the smaller ones. Both black pepper and citrus are important crops in the Guamá Microregion (Andrade et al., 2017; IBGE, 2021b). Most of the production comes from family agriculture and is widely used in the food and chemical industries, with great economic value and high profitability for both black pepper (Lima et al., 2010; Assis et al., 2015) and citrus (FAO, 2022).

Of the total area of 2211 ha, 183 ha has not yet been registered in the CAR. This value represented approximately 28% (84 ha) of the total citrus area and 31% (99 ha) of the total black pepper area. Although palm oil is the crop with the largest mapped area in the municipality, 100% is found on properties already registered in the CAR (Table 1) (Semas, 2022). The total APP area was 10,703 ha (10% of the municipality), and 25% (2665 ha) of that area was degraded (FBDS, 2022) (Figure 1).

APPs with environmental liabilities were found in 284 properties registered in the CAR (Table 2). The properties producing the three mapped crops represented 76% of the total area with a deficit in APPs. When evaluating these crops separately, the percentage varied between 75% and 80%. More specifically, farms producing citrus and black pepper showed 75% APP deficits and had a total liability area of 375 ha and 436 ha, respectively. Palm oil properties had an 80% APP deficit, which is equivalent to 439 ha. These areas may require regularization, conservation, or environmental restoration according to the current law number 12651 (Brasil, 2012).

Table 2. Permanent Preservation Area (APP) in the rural properties that produce citrus, palm oil, and black pepper in São Miguel do Guamá, Pará, Brazil.

APP with environmental liabilities	Citrus		Palm oil		Black pepper	
	Number of properties	Area (ha)	Number of properties	Area (ha)	Number of properties	Area (ha)
Absence	25	-	13	-	30	-
Presence	76	375.2	52	439.2	88	435.6
Grand total	101	-	65	-	118	-

The CAR register is a potentially promising mechanism of the Forest Code, because it establishes guidelines for areas that must be permanently preserved or conserved, such as RL and APP (Soares-Filho et al., 2014; Jung et al., 2017). Soares-Filho et al. (2014) e Jung et al. (2017) emphasizes that CAR registration is important for small producers, and the occurrence of non-registration can be due to the lack of knowledge of this tool and the means to register on their own, among other factors. The information gathered here, as well as the realization of this kind of study in the long term, will also allow for better strategies to monitor land-use dynamics and environmental regularization in private properties.

The CAR is a national electronic public registry that is mandatory for all rural properties, with the purpose of integrating environmental information on properties and composing a database for control, monitoring, environmental, and economic planning (Semas, 2022). Thus, CAR can favor the functional improvement and environmental characteristics of landscapes. For instance, habitat integrity, biodiversity, ecosystem services, and the regulation of water balance are crucial for maintaining power generation and economic incentives in the region, as the biome is crucial for the conservation of forests to reduce greenhouse gas emissions (Soares-Filho et al., 2014).

Briefly, the Instituto Brasileiro de Geografia e Estatística (IBGE) primarily gathers agricultural data through a national census that relies on questionnaires (IBGE, 2022). This approach, while official, does not accurately pinpoint the locations of the agricultural areas. Additionally, the survey involves interviewing only a few people per municipality, whose responses related to planted area and production may be estimated based on personal knowledge (IBGE, 2022). This method is adopted due to the logistical challenges of mapping permanent crops across Brazil's extensive landscape. Although our study faced certain challenges, such as time constraints and reliance on cloud-free satellite images, it utilized high-resolution satellite imagery to precisely map three permanent crops in a way that has not been done before. Our findings have the potential to enhance IBGE's Produção Agrícola Municipal (PAM) data, offering a more detailed characterization of rural properties and assisting in the development of public policies that support family farmers in accessing rural credit.

CONCLUSION

This study aims to contribute to a better understanding of the spatial distribution of mapped agricultural crops and their relationship with property sizes to better estimate the importance of these crops in the local and regional economy and environment. The data presented in this study can diverge from other platforms such as those provided by the IBGE, which relies on a census conducted using questionnaires. Instead, we conducted a supervised classification of the high-resolution images, enabling the identification of three specific perennial crops cultivated over 2211 hectares. There are rural properties that are irregular in relation to the Cadastro Ambiental Rural (CAR), except for those that produce palm oil which, for the most part of the evaluations, are large properties. In general, more than 70% of the properties lack environmental regularization for all three crops, and the degree of need for conservation and restoration is unknown, which reinforces the importance of CAR in adapting to these areas. Hence, such spatial classification helps in the development of public policies to guarantee access to rural credit by farmers, subsidize family farming in the region, and conservation actions.

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