

Spatial Analysis of Soybean and Sugarcane Monocultures in the Goiás Landscape

Análise Espacial das Monoculturas de Soja e Cana-de-Açúcar na Paisagem Goiana

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Abstract

Goiás represents Brazil as one of the most important states in agricultural production. 97% of this territory is located in the Brazilian Cerrado, an area of fundamental importance for the understanding of agriculture. The relevance of soy is closely linked to its market value, being present since the 1970s and dominating Brazilian territory, becoming popular as the main export product. Sugar cane, on the other hand, reflects the mosaic of cultures and the recent economy of Goiás. This crop presents a progressive growth based on the interest for its derivatives (ethanol and sugar) and the expansion of the sugar-energy sector in the country. This paper intends to analyze the spatiotemporal behavior of soybean and sugarcane crops in the state of Goiás between the years 1988 to 2018, using geotechnologies. The two cultures present a favorable situation and confirmed the hypotheses brought throughout the work. The use of different forms of representation and analysis aided in the understanding the South of Goiás, a mesoregion that stands out for both crops. The two cultures dominate almost entirely the Goiás lands destined for agricultural production, however, the spatial-temporal dynamics of each one of them occurs in different ways and at different times.

Keywords: Brazilian agriculture; Landscape dynamics; Representation and analysis of geoinformation

Resumo

Goiás representa o Brasil como um dos estados mais importantes na produção agrícola. 97% deste território está localizado no Cerrado brasileiro, uma área de importância fundamental para a compreensão da agricultura. A relevância da soja está intimamente ligada ao seu valor de mercado, estando presente desde os anos 70 e dominando o território brasileiro, tornando-se popular como o principal produto de exportação. A cana de açúcar, por outro lado, reflete o mosaico de culturas e a recente economia de Goiás. Esta cultura apresenta um crescimento progressivo baseado no interesse pelos seus derivados (etanol e açúcar) e na expansão do setor sucroenergético no país. Este documento pretende analisar o comportamento espaço-temporal das culturas de soja e de cana-de-açúcar no estado de Goiás entre os anos de 1988 a 2018, utilizando geotecnologias. As duas culturas apresentam uma situação favorável e confirmam as hipóteses trazidas ao longo de todo o trabalho. A utilização de diferentes formas de representação e análise ajudou na compreensão de Sul Goiano, uma mesorregião que se destaca por ambas as culturas. As duas culturas dominam quase inteiramente as terras goianas destinadas à produção agrícola, no entanto, a dinâmica espaço-temporal de cada uma delas ocorre de formas e em momentos diferentes.

Palavras-chave: Agricultura brasileira; Dinâmica da paisagem; Representação e análise da geoinformação

1 Introduction

According to EMBRAPA (2018), Brazilian agriculture was in its primary stage of land use and land cover at the beginning of the 20th century. Soybeans, which today are the main exported product, were still a curiosity in Brazil. The exponential growth of agriculture required extensive natural areas to be transformed into pasture and crop areas for the production and yields to be sufficient to keep Brazil active in this sector.

Over the last 50 years, we have noted, as portrayed in Elias (2012), the socio-spatial processes of great impact and weight on both the economy and the landscape. These processes occur mainly from the expansion of the frontier and the dynamization of agriculture and cattle ranching in the country, located mostly in the Midwest region. According to Elias (2011), the agricultural activity modifies and (re)organizes the Brazilian territory, originating new territorial arrangements, especially in the interior areas.

According to studies by EMBRAPA (2018), such as in Alves, Contini and Gasques (2008), it is possible to point out that investment in agricultural production

and productivity in Brazil began to appear in the 1960s. These investments are born through public incentives in research and development, since, at the end of the 50s, the country was going through a severe food crisis. Only with the initial investments was it possible for Brazil to move from being an importer to a supplier of food, especially of agricultural commodities for the world. Analyzing the situation of Brazilian permanent and temporary crops, Goiás is one of the states with the highest rates of production and agricultural productivity because it has an extensive area dedicated to these crops. This statement is ratified when we observe Figure 1, which highlights the importance of the Midwest in the national agricultural context, in terms of cultivated area.

We observe Goiás at the center of the spatial changes. The state presents areas with the expansion of both soybean and sugarcane cultivation. According to CONAB data released by (Bolfe, Sano & Campos 2020), there were approximately 3.5 million hectares of planted area focused on growing soybean, the country's current strongest export crop.

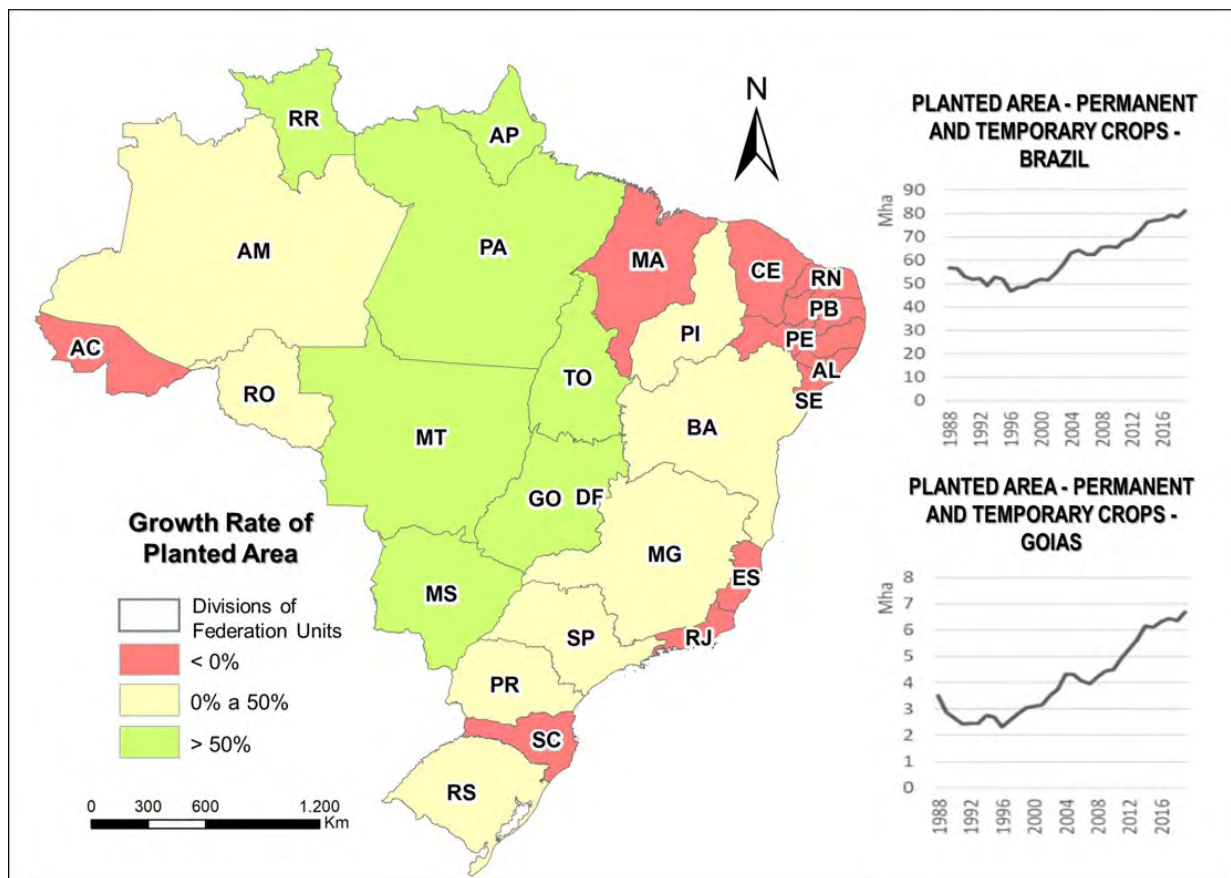


Figure 1 Map of the growth rate of planted area in Brazil. Source: IBGE

As its importance expands at a national level, current reports also address the subject, as the Spanish daily newspaper *El País* points out, soy is:

The country's main export product is experiencing a boom moment with a harvest that is about to reach a record level. More than 126 million tons of the grain will have been harvested in Brazil by the end of the 2019-2020 season (which ends in August), 7.6% more than the previous crop, according to estimates by the United States Department of Agriculture (USDA). Based on that, the country will reach the first position in the table among the main producers on the planet, replacing the United States, whose farmers have reduced their plantations because of the trade war with China the main consumer of the legume (*El País* 2020).

In addition to soybeans, the state as of the 2018 CONAB survey, has a sugarcane crop estimated at 909.8 thousand hectares, leaving Goiás as the second national producer of this crop.

Agriculture is observed as the flagship of the economic development of the Goiás state. Originally, it was self-consumption as a base, and later, after the 1970s, an advance in technologies arising from industrialization that would spread through the countryside. Thus, for this work, we analyze these two crops that are so important for the state, soy and sugarcane. They represent, together, 85% of all planted areas in Goiás, according to *MapBiomass 2020*. Furthermore, it is hypothesized, based on works such as those by (Castro et al. 2010; Castro, Garcia & Lima 2010; Leal 2015) that the two cultures are related because they occupy large territorial extensions and often dispute the same spaces, presenting strong importance in the current market.

As a result of the changes in the territory caused by the modernization of agriculture, Goiás began to present marks of regional contrasts. If, on one side, there were dozens of families of small producers, on the other, there were large transnational companies transforming the landscapes. These contrasts redefined the Cerrado biome scenario which, initially, was seen as unproductive and became a land of extensive commercial monoculture plantations, mainly soy and sugar cane. These changes are considered, therefore, as part of a broad study understood as landscape dynamics. The landscape, according to (Matos & Maia 2018) "is the process resulting from the society-nature relationship, which offers resources that are transformed by society to meet its demands." As society modifies the landscape through its uses and occupations, a series of new dynamics are configured within it.

Besides the authors mentioned above, we also bring the study by (Bertrand 2004) in which he understands

landscape as not a simple conjunction of geographical elements, but the dynamic, stable combination of physical, biological, and anthropic elements, because the landscape is not the only natural, but total, with all the implications of human participation. (Bertrand 2004)

Linked to the concept of landscape dynamics, we also work with evolutionary trajectories, because they allow us to identify, according to (Weckmüller, Slovinski & Vincens, 2013) the history of each land use and land cover over time, helping in the understanding and spatialization of each of the changes. To understand the possible temporal patterns of changes in use and cover and evolution of the landscape itself, it is necessary to describe and analyze the processes that influence the dynamics through the historicity of use and cover.

For this paper, the concept of evolutionary trajectory becomes indispensable when we observe the rapid and dynamic change of the landscape of Goiás. Because based on it, we will seek compression of the dynamics of each study area, as well as areas with more evident changes. However, spatially representing studies of land use and land cover dynamics and landscape evolutionary trajectories is quite complex, since a diversity of statistical data is used to compose the final result. Elaborating scenarios, predicting hypothetical situations using statistical data can only be possible thanks to the cartographic tools used nowadays. Martinelli (2005) highlights the interest of cartography in understanding spatial aspects changing over time. According to the author, changes occur in two different ways, being:

The states of spaces can change: soil erodes, lakes freeze over, and living things are born, grow, and die. Second, a spatial position can change over time. Also, some things move by themselves, others are driven by external forces. The result of the diffusion of objects, ideas, techniques, information in space is the continuous change of its configuration. Changes in both state and position have two components: the speed of change and the way this change occurs over time. (Martinelli 2005)

Besides the mentioned, the cartographic contribution essentially helped in the understanding of the spatial behavior of soybean and sugarcane crops over a period equivalent to 30 years of analysis. Using cartography as a scientific method is, in this way, to be able to build, fundamentally, for us geographers, analyses of spatial patterns, since "cartography has a technical dimension committed to the precision and accuracy of representations" (Menezes & Fernandes 2013). For this research, the cartographic approach allows a satisfactory understanding of the evolutionary trajectories and dynamics of the landscape, helping as a tool for understanding the space and spatial relationships of crops.

In addition to cartography, it was extremely relevant to work with the concept of geotechnologies that allow the understanding of the representations of the dynamics and evolutionary trajectories. According to Rosa (2005), geotechnologies act as a set of technologies for collecting, processing, analyzing, and providing information with geographic reference. They are composed of hardware, software, and peopleware solutions. Geotechnologies enable, in turn, a spatial analysis that is understood “as a phenomenon under study that varies in space” (Câmara, Davis & Monteiro 2001)

One of the important geotechnologies used in the preparation of this research was the spatial analysis of geographic data. According to (Druck et al. 2004), the spatial analysis seeks

measuring properties and relationships, taking into account the spatial location of the phenomenon under study in an explicit manner. This means that the central idea is to incorporate space into the analysis that one wishes to make. (Druck et al. 2004)

For this research, the type of spatial analysis chosen is characterized by point events or patterns, which according to the aforementioned authors is defined by “phenomena expressed by occurrences identified as points located in space, called point processes”.

In this context, this research seeks to answer some questions that are essential to the understanding of the evolution and transformation of the landscape of Goiás, from the perspective of agricultural dynamics. In the first moment, it focuses on answering: (i) how is the evolution

of soybean and sugarcane crops in Goiás in the time frame from 1988 to 2018? (ii) do the crops have measurable and amenable patterns for analysis? and (iii) is it possible to point out relationships between the dynamics of the two crops?

To answer these questions, the general objective seeks to analyze the dynamics of the landscape from the spatial-temporal behavior of soybean and sugarcane in Goiás (1988 - 2018). To do so, it was necessary to (1) understand the spatial-temporal behavior of soybean and sugarcane crops in Goiás in the period from 1988 to 2018; (2) analyze the possible spatial patterns existing in the path of the crops over 30 years; (3) analyze the possible spatial relationships between the dynamics of the two crops over 30 years.

2 Study Area

The state of Goiás is located in the Midwest region of the Brazilian territory, in an area of 340,203.329 km². Its territorial limits are between the northern Tocantins, south with Mato Grosso do Sul and Minas Gerais, west with Mato Grosso, and east with Bahia and Minas Gerais, as can be seen in Figure 2. Its estimated population according to the last census of 2010 from IBGE is 6,003,788 people, with a demographic density of 17.65 hab/km². For this work, it was important to take into consideration the territorial divisions of Microregions and Mesoregions. These two forms of the intra territorial organization helped in the spatial analyses carried out, highlighting patterns on an intermediate scale to the state and municipal clippings.

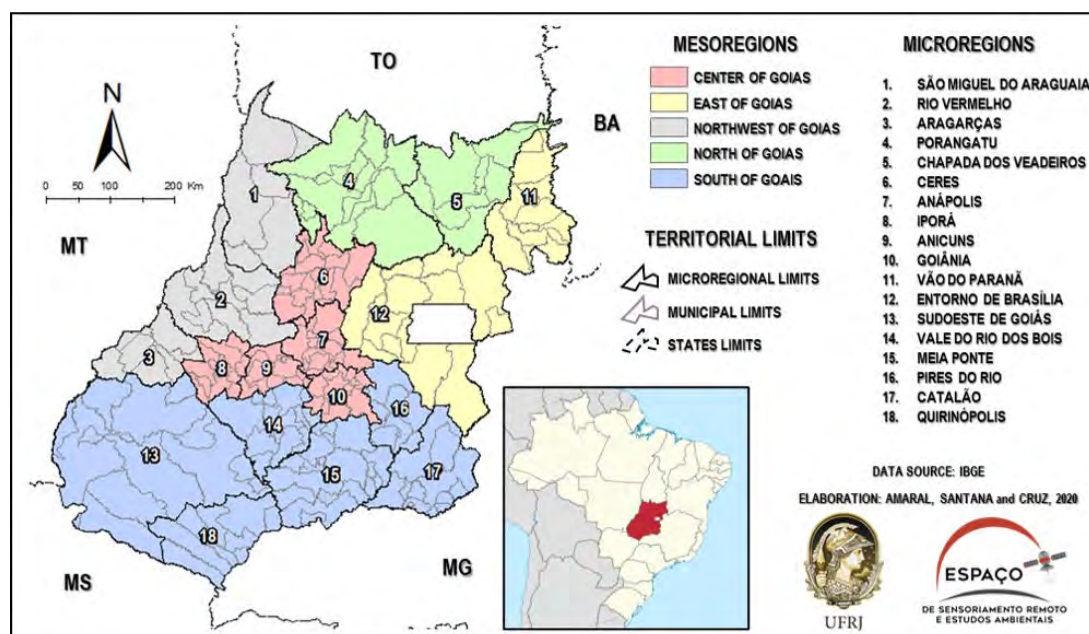


Figure 2 Study area location map

Regarding the physical aspects, Goiás has a tropical climate with two well-defined seasons, a dry and a rainy period. Its relief, for the most part, is flat land, with natural fertility that varies from low to high, with predominant soil of the Latossolo group. Regarding hydrography, the state of Goiás has three important hydrographic regions, being Tocantins/Araguaia, São Francisco, and Paraná.

As for the vegetation, Goiás covers an area with approximately 97% of the Brazilian Cerrado, being the federation unit with the largest incorporation in the physiographic limits of this biome (IBGE 2020a). According to (Myres et al. 2000) this biome is one of the main and most important hotspots on Earth, corresponding to approximately 22% of the national territory, involving the states of Mato Grosso, Minas Gerais, Bahia, Mato Grosso do Sul, Maranhão, Rondônia, Piauí, São Paulo, Paraná, Distrito Federal, Tocantins and Goiás.

3 Methodology and Data

The methodological steps of this research consisted in obtaining secondary census data based on the variable “Planted Area (ha)”, the digital mesh of the state of Goiás, as well as its micro and mesoregional divisions and territorial limits. Then, the data processing began with the proposed analysis and the making of maps, graphs, and tables, with the help of ArcGIS and Excel software, as shown in the flowchart below (Figure 3). The following will present the main steps of the research as shown in the flow chart above.

For the initial development of this research, we first sought secondary data in the SIDRA base available in the platform of the Brazilian Institute of Geography and Statistics (IBGE). These are aggregated data from surveys conducted by the Institute regarding the Municipal Agricultural Production available in table 5457: Planted Area Variable.

The variable planted area is represented by the area in hectare (ha) occupied by agricultural products. The products of temporary and permanent crops chosen for this analysis were only soybeans and sugarcane. The data collected refer to the federation unit Goiás, its municipalities, mesoregions, and geographic microregions between the years 1988 and 2018.

Subsequently, it was necessary to carry out a procedure to make the boundaries and attributes compatible, in order to respect all the spatial changes resulting from the emancipation of a group of municipalities. For this, the work was based on the territorial base of 1991, and all the values referring to the municipalities emancipated after 1991 were reintegrated to the municipalities to which they belonged.

The database of the State System of Geoinformation in Goiás (SIEG) helped to understand the territorial limits and regional divisions of Goiás, as well as what and where its micro and meso-regions were located.

Spatial/cartographic and statistical classifications were defined as an analysis model for the construction of this research. As a way to classify the variables spatially, we started the elaboration of trajectory maps based on the municipality of Goiás and its territorial divisions. The trajectory maps are defined as methods for understanding studies of annual spatial dynamics (Santana, Amaral & Cruz 2020; Clemente et al. 2017; Hermuche et al. 2013; Vicens, Cruz & Amaral 2021) based on vectors and tabular data from ArcGis 10.3 and Excel 2016 software.

This map is prepared by calculating the centers of mass from the centroid extraction (Equations 1 and 2). The midpoints are created based on the centroids that result from a weighted average of the location per municipality with its planted area. In this way, as a municipality grows in a planted area, the more it will “pull” its centroid.

$$\rho media = \frac{\sum(\varphi mun.(x))}{\sum(x)} \quad (1)$$

$$\lambda media = \frac{\sum(\lambda mun.(x))}{\sum(x)} \quad (2)$$

In addition to the trajectory maps described, thematic maps of the entire state of Goiás were created, which aimed to generate representations of geographic information, such as the spatial-temporal change of the vegetation cover of Goiás. These thematic mappings were created from previously performed statistical analyses that were defined as an analysis of variance, sum, amplitude, trend, and centers of mass.

The analysis of the coefficient of variation or relative standard deviation corresponds to a standardized measure of dispersion of a frequency distribution (Equation 3), that is, it aims to demonstrate how unstable the series is, that is, to inform whether or not there is constancy in a given city over time.

$$CV = \frac{\sqrt{\frac{\sum(x - M(x))^2}{n}}}{M(x)} \quad (3)$$

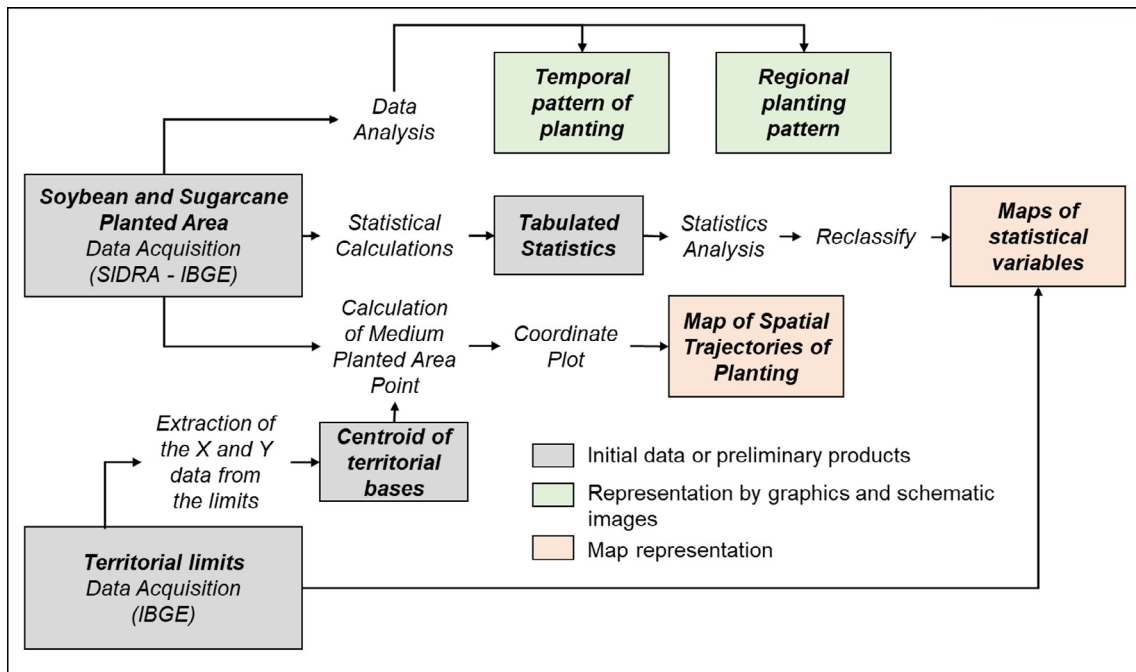


Figure 3 Flowchart of the methodological steps.

The range is a measure of dispersion used in statistics to understand a given set from the difference between the smallest and largest element used (Equation 4). For this research, the amplitude gives us the intensity of change in a single municipality in the series.

$$RANGE = Max(n) - Min(n) \tag{4}$$

It is a statistical measure that corresponds to the sum of several elements of a set. In this case, the sum is associated with the importance of the planted area of a given municipality in Goiás, meaning that the greater the sum of a given area during the time frame of the research, the more representative this area will be (Equation 5).

$$SUM \sum(x) \tag{5}$$

To make this more similar to reality, it was necessary to find insignificance thresholds for each of the crops, with values less than 1500 ha for sugarcane, and less than 8500 ha for soybeans. In statistics, we call a trend a central value for a given probability distribution. For this case, we seek to understand the overall change in a given municipality, that is, whether the future trend happens in the form of growth or reduction of the planted area (Equation 6).

$$TREND = \frac{(x_{final} - x_{initial})}{(n) - (n)} \tag{6}$$

4 Results and Discussions

4.1 Analysis of the Continued Growth of Soybeans and Sugarcane

Based on the values of the areas planted with soy and sugarcane crops in graphs, one can observe continuous growth during the 30 years of analysis. This growth, although constant, presents itself in a differentiated form when compared and analyzed together, as shown in Figure 4. Soy initially grows strongly in the period from 1996 to 2005, vigorously related to technological and input innovations (Cunha & Espíndola 2015). Sugarcane, in turn, shows an effective growth between the years 2007 and 2014, responding to the advance of the sugar-alcohol industry in the Midwest of the country, corroborating the statements of Lima & Garcia (2011) also showing that this increase has been maintained to the present day.

Another observation about the analysis of the crops concerns the temporal correlations that can be observed. It is possible to observe that at the time of greatest growth in the sugarcane harvest, soy presented its greatest decrease (between 2004 and 2008). This behavior can help us understand some spatial dynamics throughout the article, especially this initial competition.

To understand the spatial-temporal dynamics of the crops in the state, it was first necessary to locate the

main areas of incidence of each of them. From Figures 5A and 5B which show the ten municipalities with the largest planted area of each crop, it is possible to understand the importance of the South region of the state. Plantation areas are located substantially in municipalities of this mesoregion as presented in Lima et al. (2014), being the largest Rio Verde (for soybean) and Goiatuba (for sugarcane). In Figure 5C it is also possible to understand how the mesoregions behave from the perspective of these crops.

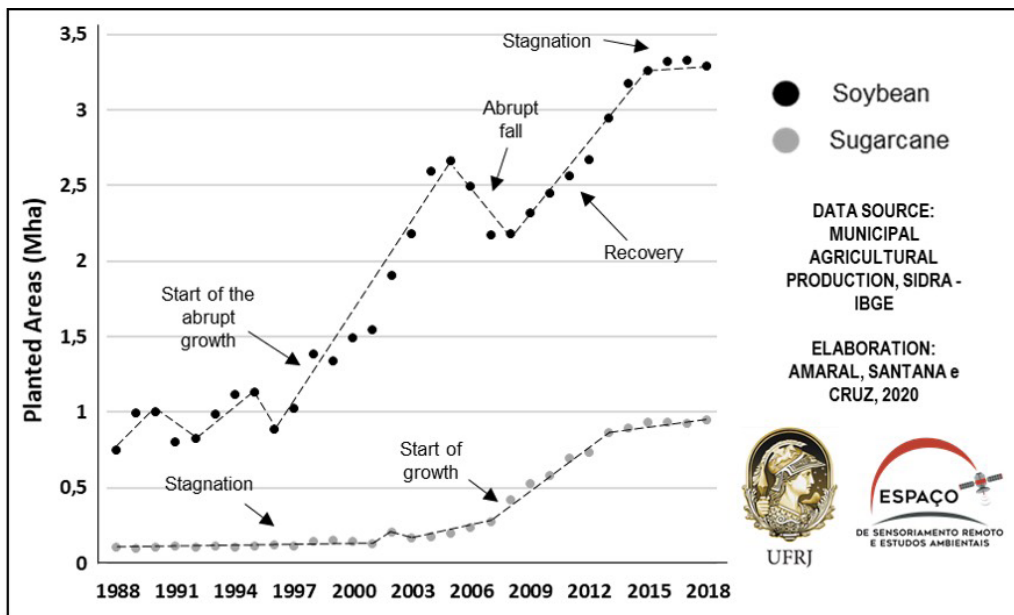


Figure 4 Evolution of agricultural crops in the time frame

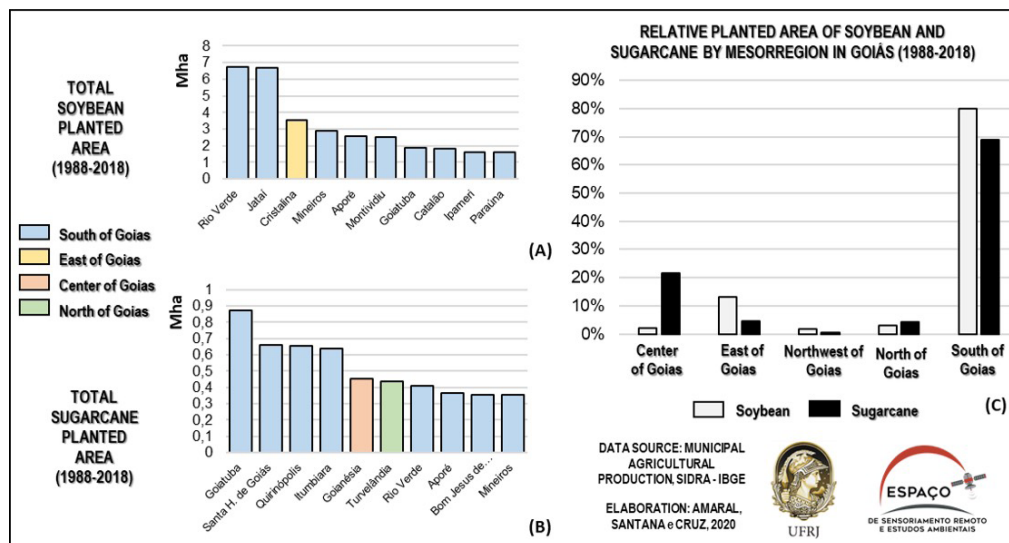


Figure 5 A. Ten largest soybean plantation areas; B. Ten largest sugarcane plantation areas; C. Relative planted area by mesoregion.

4.2 Analysis of the Trajectory Maps

Analysis of the centroids trajectories for each crops (from year to year) presented distinct spatial behaviors, as can be seen in Figure 6. Although there is a strong deployment of soybean and sugarcane in Goiás, both the spatial dispersion and temporal dynamics were not the same. Both are concentrated in the South of Goiás (Figures 6A and 6B), however, we can observe a reallocation of sugarcane planting over time, while soy is more inert compared to the former.

In relation to the trajectories, it is clear that over time sugarcane moves more and more towards the south. Soy, on the other hand, has opposite dynamics between the first part of the time frame and the second. Observing the years between 1988 and 1998, soy tends towards the east and changes completely in the final years of the analysis, going towards the east. This is a clear sign of decentralization, that is, in recent years, the most southwestern part of the state has the largest soybean cultivars.

This dynamic becomes more explicit when we observe the graphs in Figure 6C, which shows the predominance in the South of Goiás in these two crops, for soybean since the beginning of the study and for sugarcane as of 2007. When highlight soybean, it can also be observed that the mesoregion called East of Goiás ends up gaining space when the soybean planting starts to go south in mid-2006/2007, and its rise becomes continuous and today it reveals itself as one of the areas of soybean dominance. Sugarcane, on the other hand, shows accelerated growth as of mid-2005 in the South of Goiás and putting in stagnation the curve of the Center of Goiás.

As observed, the South of Goiás is the most relevant region for the study, since it concentrates the cultivars of the two crops chosen here for the analysis. Therefore, it was extremely necessary to understand the performance of soy and sugarcane in this mesoregion. To this end, we highlighted the mesoregional scale in the South of Goiás, observing more precisely these crops performance in this space (Lima et al. 2014).

Differently from what was observed in the evolutionary trajectories for the entire state, when we close the analysis in the South of Goiás, changes in dynamics are noted. The recovery of the beginning of the period seen in the state is also represented for the mesoregion, with soybeans in the East-West direction. But there are significant changes at the end of the period, soybeans are almost inert, which implies that the greatest dynamics that occur in the state happen due to the growth of cultivars in the East of Goiás mesoregion.

Sugarcane almost rebuts entirely the dynamics of the state in those of the southern mesoregion, this can be explained due to the discrepancy between the planting areas between South and Center of Goiás (Figure 7B). Some differences are seen at the beginning of the time period, especially before the year 2000, which ratifies the cause of the correlation, since this is the moment when the quantitative figures of the two mesoregions are similar. Thus, the sugarcane follows the northeast-southwest pattern, with small deviations in the middle of the period to the northwest and southwest.

Besides the analysis by mesoregion, graphs were created from the micro-regions of the South of Goiás (Figure 7C), showing their performances and the importance of each one for each chosen crop. As expected, the progress of the Southwest of Goiás was observed for both soy and sugarcane. Soy, as said, showed strong development, stagnating in the most recent years, while sugarcane expanded and disputes spaces with soy.

4.3 Statistics Maps of South of Goiás

These last two analyses complement each other, showing the advance of sugarcane to the Southwest and its concentration in the micro-regions to the West of Sul Goiás (Southwest of Goiás, Quirinópolis, Vale do Rio dos Bois and Meia Ponte). Soybean is strongly concentrated in two mesoregions (Southwest and Meia Ponte) and has been growing in the other microregions, which stabilizes its midpoints as seen earlier thus going against previously elaborated works by several other authors (Borges 2013; Barbalho, Silva & Castro, 2013; Pedroso, 2004).

The hypothesis of accelerated growth of sugarcane together with its spatial dynamics is ratified by the statistical analysis of the series from the sum, amplitude and trend. As well as the stagnation of soybean and its decentralization. This analysis highlights the municipalities with the largest soybean planted area (Jataí and Rio Verde) that do not have high trends and in other municipalities even negative. This is contrary to the accelerated growth of soy in recent years in the state, reinforcing the concentration of soy in the West of Goiás at the beginning of the period and a current migration of soy towards the east (Figure 8).

As for sugarcane, the growth in the Southwest is very explicit in the maps of Figure 9, and this becomes clear by analyzing the maps of sum, amplitude, and tendency together. The mesoregion presents municipalities with a large amplitude (where there was no planting, it begins to appear), followed by positive and significant maximum

tendencies, as shown in the sum. Thus, there are new municipalities with notoriety and a concentration of their cultivars in this area. The coefficient of variation signaled the constancy and inconstancy of the municipalities, while

the trend highlighted the municipalities that showed growth or reduction in planting. As an example, we observe that in Figure 9 more municipalities tend to expand, while in Figure 8, soybean shows an opposite behavior.

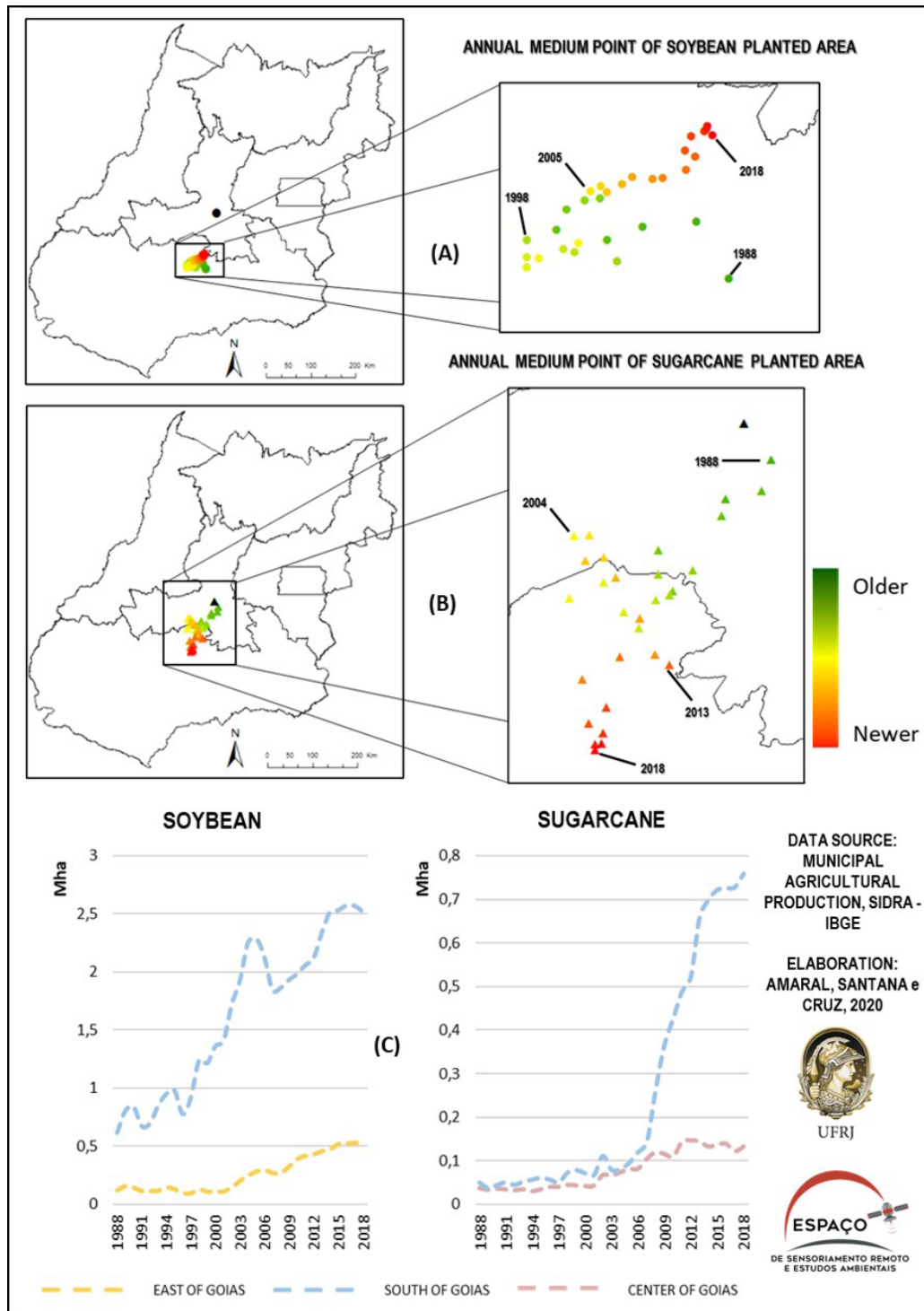


Figure 6 A. Soybean annual planted area; B. Sugarcane annual planted area; C. Planted area evolution in mesoregions of the state of Goiás.

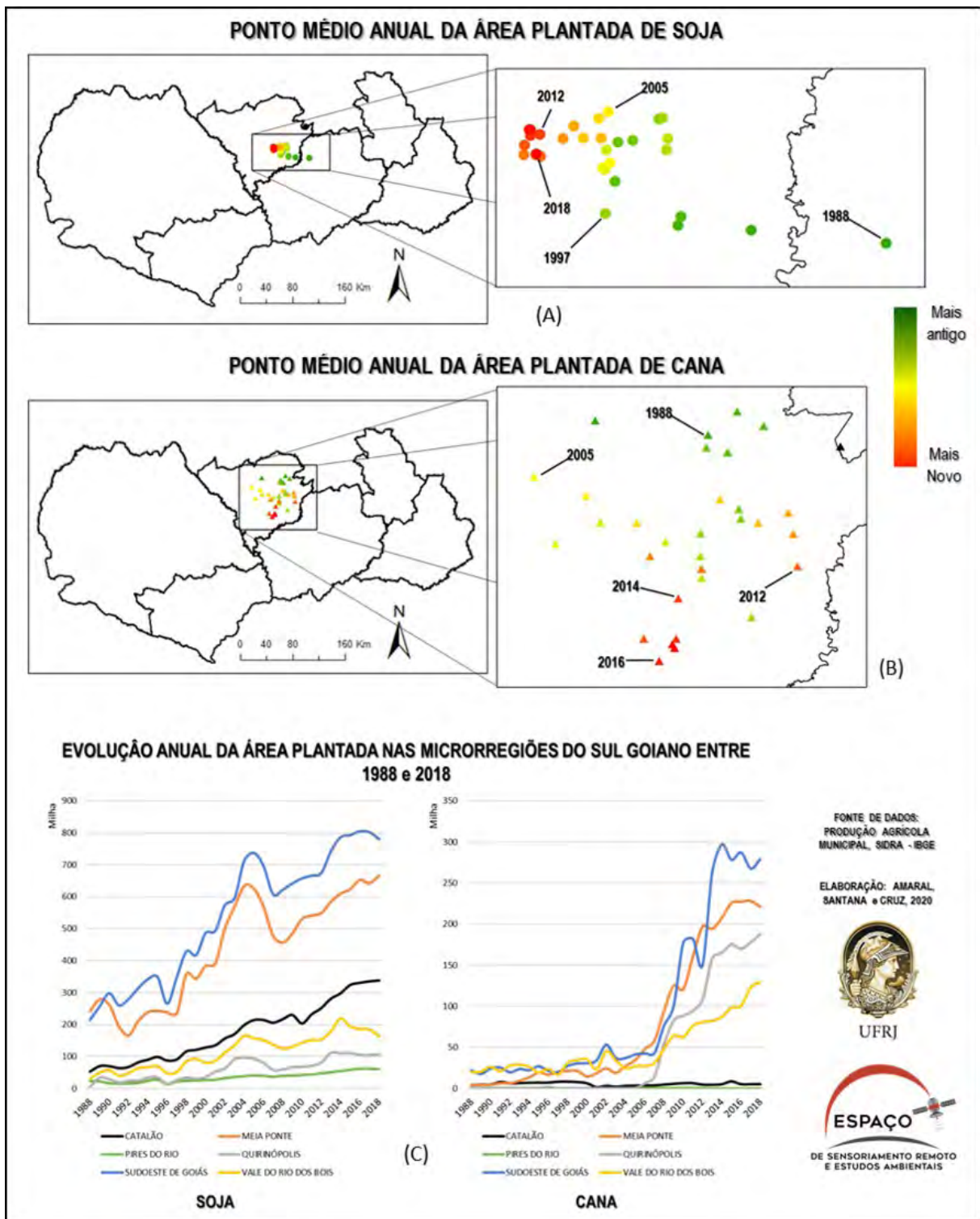


Figure 7 A. Soybean annual planted area; B. Sugarcane annual planted area; C. Planted area evolution in microregions of South of Goiás.

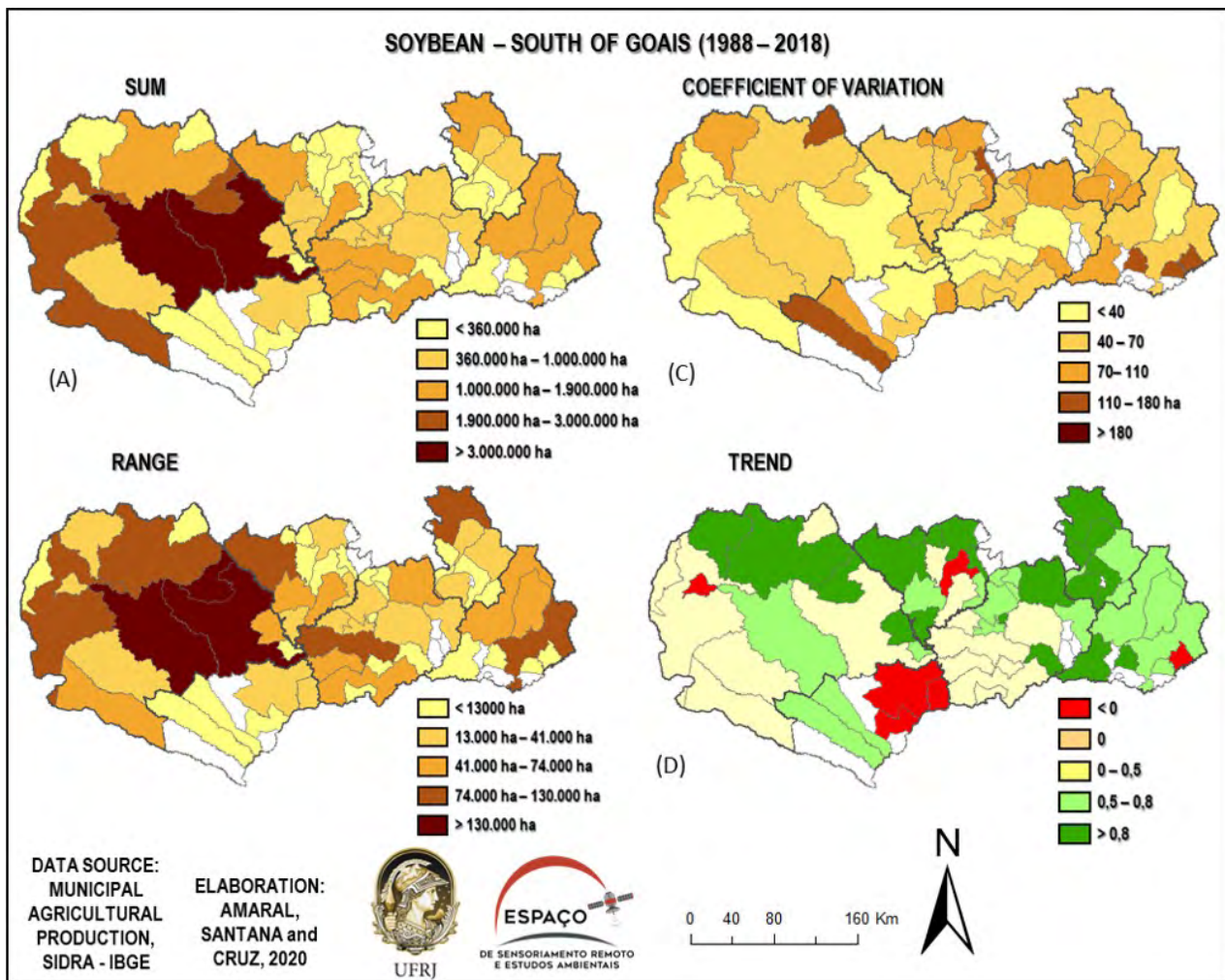


Figure 8 Analysis of the constant: A. Sum; B. Range; C. Coefficient of variation; D. Trend, highlighting the dynamism of soybean in the South of Goiás (1988 to 2018).

5 Conclusion

It was observed throughout the research the success of the methods used to understand the functioning of soy and sugar cane plantations in the state of Goiás. The two cultures are in a situation of similarity, that is, expanding their areas of influence. In this way, all the hypotheses proposed on the three chosen scales are confirmed. The use of different forms of representation and analysis helped in the perception of the importance of the South Goiás, more precisely, in the Southwest, which demonstrated effective expressiveness of growth.

Both crops hold a large portion of Goiás’ land, dominating almost entirely the planted areas. The spatial-temporal dynamics of each one of them happen in different ways and moments. The “confrontation” between the two crops happens when there is a technological and economic change at a certain moment. So, while soy stagnates and changes its pattern of spatial dispersion, sugarcane expands and concentrates in areas where before the other crop was the only one. With this scenario, soy tends to disconcert its areas of influence, moving towards the East, while sugarcane leaves the Center towards the South of Goiás, reaching several micro-regions.

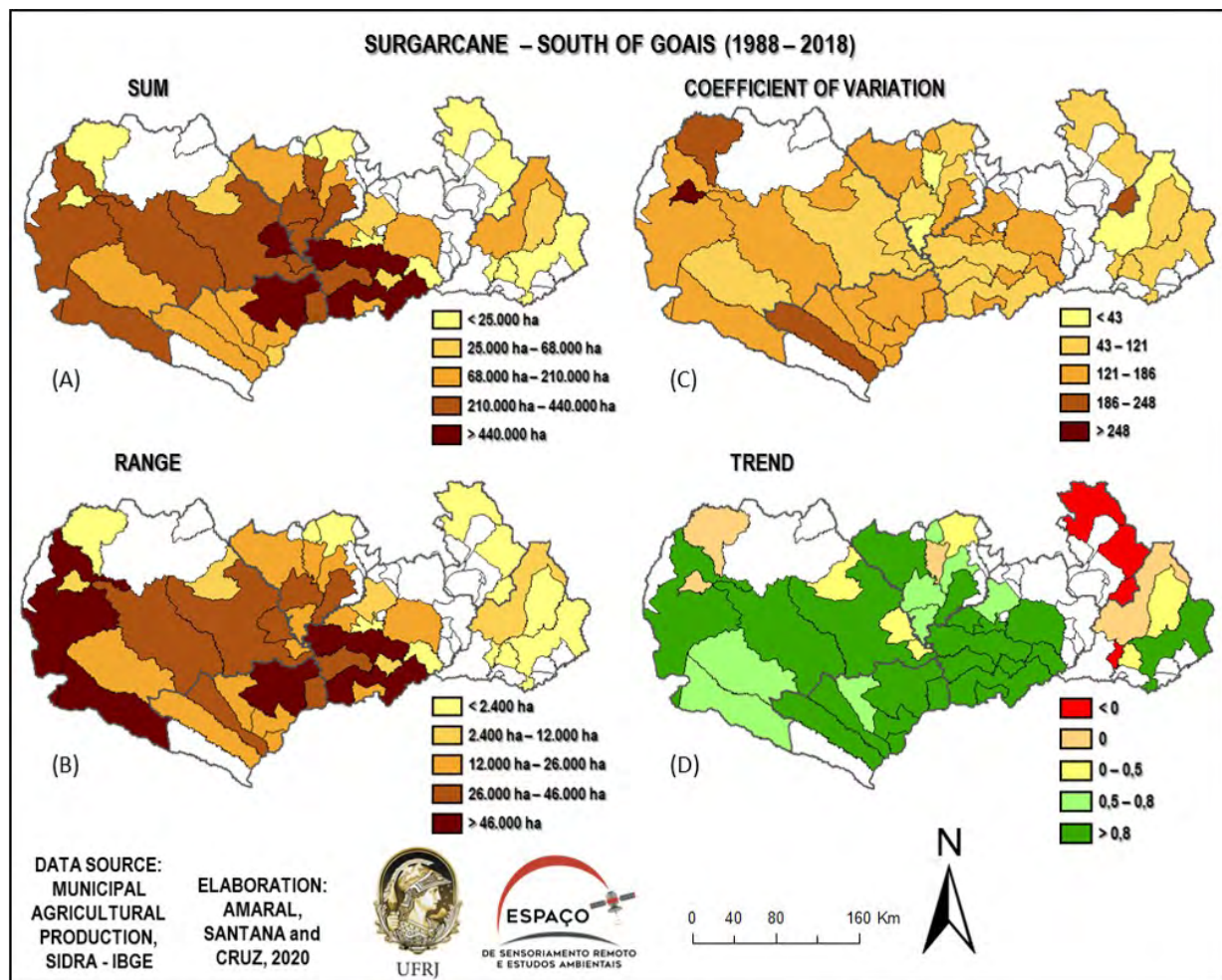


Figure 9 Analysis of the constant: A. Sum; B. Range; C. Coefficient of variation; D. Trend, highlighting the dynamism of sugarcane in the South of Goiás (1988 to 2018).

To look at sugarcane and soy is to understand how these crops impact the dynamics of the national territory and how public policies manage the socio-economic functioning of this state and the country as a whole. Understanding the relevance of the growth of soy and sugarcane plantations in Goiás may incite the perception of studies on the deforestation that affects the Cerrado. As a way of sustaining these hypotheses brought forth throughout this work and ratifying these thoughts, the next steps intend to analyze the dynamics of sugarcane and soy cultivation in other uses and covers and in other related crops.

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Author contributions

Beatriz da Silva Feitoza Santana: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Felipe Gonçalves Amaral:** formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Carla Bernadete Madureira Cruz:** writing – review and editing; supervision.

Conflict of interest

The authors declare no potential conflict of interest.

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All data included in this study are publicly available in the literature or in the respective data repositories.

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