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# Change analysis of coffee soil cover in the state of Parana: a case study

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ABSTRACT
Coffee is a crop of great agronomic interest worldwide. It is one of the most negotiable tropical products, and it has been gaining "specialty" status around the world, with increasing number of plantations in places with Geographical Indications. Studies show that coffee has been undergoing recent changes in planting area, due to different economic, social, cultural, and climatic reasons. The change of in the planted area of a crop causes many different events; among them, the substitution of it for other agricultural crops. As such, sugarcane is a crop that has been recently gaining space, as its planted area increased considerably. In this sense, this work sought to analyze the change in the use and occupation of coffee soil in the State of Paraná between 1998 and 2018, comparing it with the change in the use of sugarcane soil; with altitude; and with regions with indication of source in the state. The results suggest a reduction of 92.29% of the planted area of coffee and an increase of 289.87% in the planted area of sugarcane. The results also suggests that coffee was replaced by sugarcane in some sites. The remaining coffee plantations were concentrated in the region of indication of source in the Northern region of the state, which has lower altitudes.

KEYWORDS
Planted area. Coffee. Retraction. Replacement.

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## 1. Introduction

Coffee is a crop of great agronomic interest worldwide. It is one of the most negotiable tropical products, and has been gaining "specialty" status around the world, especially considering the great amount of gourmet coffee beans on the market (Alfonsi et al., 2019). According to Iscaro (2014), in agreement with Davis et al. (2012), coffee is, after petroleum, the most commercialized commodity in the world. According to the Food and Agriculture Organization (FAO), in 2019, the world's production of green coffee beans surpassed 10 million tons, over 11 million hectares. As is the case worldwide, coffee has a historical significance in Brazil; the country was the largest producer in the world with 3 million tons in 2019. (FAO, 2021). In national production, the State of Parana occupies the sixth largest production, with 63,300 tons in 38,000 hectares (IBGE, 2021). Geographical Indications (GI) further contribute to the appreciation of coffee, as they add value to the product and establish a competitive differential in the market; furthermore, they also protect the identity of the product as well as the touristic and cultural promotion of the region (Giesbrecht & Minas, 2016). An important region of the State of Parana is its "Norte Pioneiro" (in English: "Pioneer North"), a region with indication of source that produces differentiated coffees. As stated by Art. 177 of Law 9,279 of 1996, a region with Indication of Source is a location that has become known as a center for the extraction or production of a certain product (Brasil, 1996). According to the Association of Special Coffees of the "Norte Pioneiro Paranaense" (ACENPP), the coffees produced in this region have a creamy body, high sweetness, citric acidity, and flavors and aromas that refer to chocolate, caramel, molasses, and honey.

Bongase (2017) states that coffee requires specific environmental conditions in order to be economically viable. Climate variability is one of the main factors of oscillation and frustration in coffee productivity in Brazil, especially in Sao Paulo, Minas Gerais, Espirito Santo, and Parana (Camargo, 2010). In addition to the natural variability of the climate, or even the possible changes in the trends of meteorological variables, other economic, social and cultural factors end up affecting the decision of producers regarding the use of their land (Haggar et al., 2013). Thus, it is necessary to diagnose the change in use and occupation of coffee soil for a better understanding of the facts. To Mulianga et al. (2015), the use of geotechnology for mapping arable areas is essential in this type of study, as it is able to provide accurate and fast data.

Changing the coffee area may also lead to changes in the local landscape. Crop retraction can, for example, promote the advancement of other crops, thus replacing agricultural crops and resulting in possible interferences in food security. In Nicaragua, large properties located at low altitudes replaced coffee areas with pastures, fruit, and rubber trees, while medium-sized properties exchanged coffee for corn, bananas and other crops (Haggar et al., 2013). As for Brazil, in the State of Sao Paulo, between 1990 and 2013, there was a great abandonment of coffee production (Coltri et al., 2019). In this context of crop substitutions, sugarcane, the third most produced crop on the planet (FAO, 2021), has gained prominence, as a major substitute for other agricultural productions (Ronquim & Fonseca, 2018). The advance of sugarcane in Brazil has occurred in several Brazilian states, such as Sao Paulo (Rudorff et al., 2010), Mato Grosso do Sul (Assunção et al., 2016), Goias (Spera et al., 2017) and Parana (Ribeiro et al., 2013). The reasons for such advance are mainly related to one of the main by-products of the crop: ethanol (Zullo et al., 2018). In Brazil, ethanol receives large government incentives for its production (Martinelli & Filoso, 2008), as it is one of the most promising biofuels (Oliveira et al., 2005).

As such, our work sought to evaluate the change in the use of coffee cover in the State of Parana between 1988 and 2018, considering the following hypotheses: (i) there was a retraction of the planted area of coffee in the state; (ii) this retraction is related to the substitution of the coffee crop by sugarcane; and (iii) factors such as altitude and regions with indication of source positively interfere in the concentration of coffee areas.

## 2. Materials and Methods

The methodology of this work consisted of three stages: (i) planted area database, (ii) geospatial analysis and (iii) data analysis and correlation.

### 2.1. Planted area database

We used the SIDRA statistical information database provided by the Brazilian Institute of Geography and Statistics (IBGE), in order to compose the planted area database, in hectares, for each municipality in Parana. The planted area data for both coffee and sugarcane were extracted for a series of 30 years between 1988 and 2018. The data were organized in municipality × year format. For the analyses, data from both crops were

selected every five years, starting in 1988. Therefore, the analyses of planted areas were carried out on the years 1988, 1993, 1998, 2003, 2008, 2013 and 2018. Additionally, a percentual change index (PCi) was performed in the data, following Formula 1, as described by Berry (1993).

$$PCi = (Pcur - Ppre)/Ppre \times 100 \quad (1)$$

Pcur was the last year of study (2018) and Ppre, the first year of study (1988). The analysis was thus carried out with planted area data for both coffee and sugarcane. The possible results are positive percentages, showing the increase of the planted area, or negative percentages, demonstrating the partial or total decrease of the planted area.

### 2.2. Geospatial Analysis

For the geospatial analyses, the municipal, mesoregional and territorial meshes of the Parana provided by IBGE were used. The software used for the elaboration was the QGis version 3.10. Firstly, the planted area data of the chosen years in the municipal mesh were geospatialized according to the following classes: 0 ha; 1 to 100 ha; 101 to 1500 ha; 1501 to 3500 ha; 3501 to 5500 ha; 5501 to 12500 ha and 12501 to 30000 ha. The same classes were monitored for both coffee and sugarcane.

### 2.3. Data Analysis and Correlation

The general analysis of the data was carried out under three aspects: the possible substitution of coffee crops by sugarcane, described in 2.3.1; understanding the relationship between coffee migration and altitude, described in 2.3.2 and, finally, understanding the relationship between coffee crop migration and regions with indication of source for cultivation in the state, described in 2.3.3.

#### 2.3.1. Correlation of crop substitution

Using the PCi values for the crops, we analyzed the municipalities that presented growth of the planted area of sugarcane and decline of the planted area of coffee simultaneously. These municipalities were selected and geospatialized in the municipal mesh, which then led to the crop substitution map.

#### 2.3.2. State hypsometry × coffee planted area

With the territorial mesh of the state and the images of the DEM (Digital Elevation Models) provided by the USGS (United States Geological Survey), it was possible to perform a hypsometric map of Parana with the following classes: 0 m; 200 m; 400 m; 600 m; 800 m; 1000 m; 1200 m; 1400 m; 1600 m and 1800 m.

From the state hypsometry map, it was possible to combine the data of planted area of coffee crops geospatialized in the municipal network. Thus, for each year chosen for study, it was possible to obtain a new map relating the areas of coffee crops to the altitude of the site.

#### 2.3.3. Regions with indication of source for the cultivation of coffee

Using the mesoregional mesh of the State of Parana it was possible to indicate the "Norte Pioneiro of Parana" as an area with Indication of Source (INPI s.d.). This region is composed of 45 municipalities: *Abatiá, Andirá, Assaí, Bandeirantes, Barra do Jacaré, Cambará, Carlópolis, Congonhinhas, Conselheiro Mairinck, Cornélio Procópio, Curiúva, Figueira, Guapirama, Ibaiti, Itambaracá, Jaboti, Jacarezinho, Japira, Joaquim Távora, Jundiaí do Sul, Leópolis, Nova América da Colina, Nova Fátima, Nova Santa Bárbara, Pinhalão, Quatiguá, Rancho Alegre, Ribeirão Claro, Ribeirão do Pinhal, Salto do Itararé, Santa Amélia, Santa Cecília do Pavão, Santa Mariana, Santana do Itararé, Santo Antônio da Platina, Santo Antônio do Paraíso, São Jerônimo da Serra, São José da Boa Vista, São Sebastião da Amoreira, Sapopema, Sertaneja, Siqueira Campos, Tomazina, Uraí,* and *Wenceslau Braz.*

## 3. Results

### 3.1. Decrease in the coffee planted area

Figure 1 shows the results of the change in coffee planted area in Parana for the analyzed temporal window. We verified that, in 1988 (the initial year of the series), the state had 505,369 hectares of coffee planted area. At the end of the series, in 2018, this was reduced to only 38,958 hectares. The data suggest that there was a

92.29% reduction in coffee planted area over 30 years. However, this reduction in area was not homogeneous and constant. Between 1988 and 1993, the largest reduction occurred, of 56.4%. Considering the first ten years of analysis (1988 - 1998) the reduction was 74.6% in the planted area of the state. Between 1998 and 2003 there was a very small reduction, of about 1.3%; and, in the years 2003, 2008, 2013 and 2018 the decrease of planted hectares occurred more constantly, on average, 32% every 5 years, according to Figure 2.

Figure 3 shows the Change Index, indicated by the PCi, from the State of Parana. We verified that of the 210 municipalities that had some PCi value, only three had an increase in the coffee planted area. Among the 207 municipalities that decreased its planted area of coffee, 41 completely abandoned coffee cultivation, and another 147 municipalities had a decrease of at least 76% of coffee planted areas.

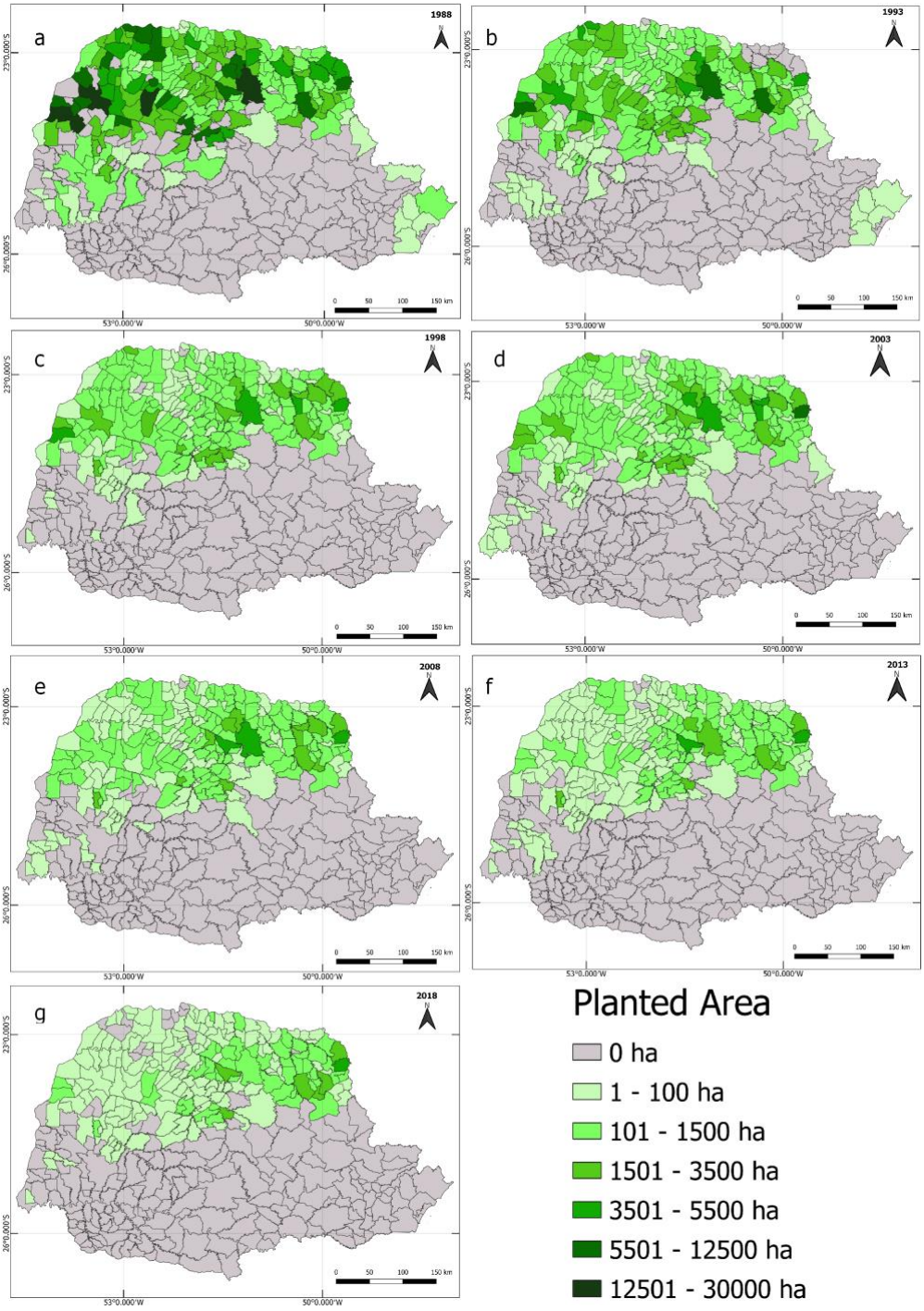


**Figure 1.** Coffee planted area in the State of Parana in the years 1998 (in "a"), 1993 (in "b"), 1998 (in "c"), 2003 (in "d"), 2008 (in "e"), 2013 (in "f") and 2018 (in "g").

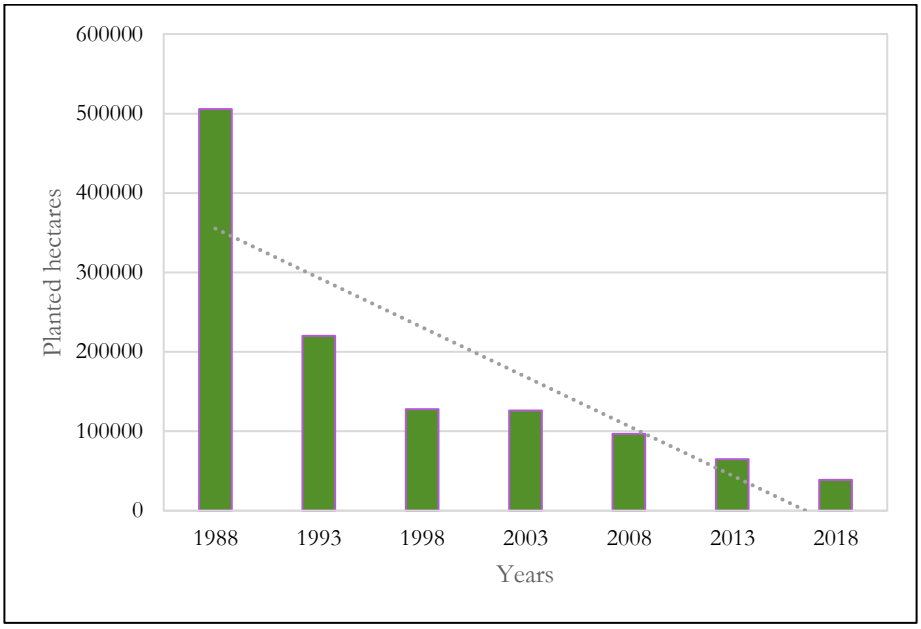


**Figure 2.** Evolution of the coffee planted area in the State of Parana.

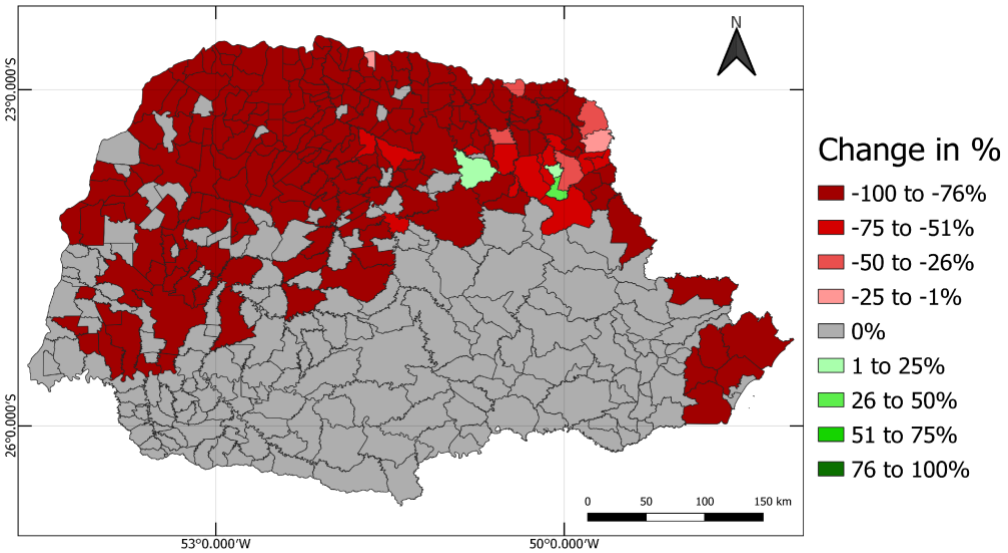


**Figure 3.** Change Index of the State of Parana for coffee crops.

### 3.2. CHANGE IN THE PLANTED AREA OF SUGARCANE

Figure 4 shows the sugarcane planted area in the State of Parana in the analyzed time series. We verified that, at the beginning of the study period, Parana had 157,355 hectares of planted sugarcane. At the end of the studied series, the state had 613,487 hectares. These results suggest an increase of 289.8% in planted area of sugarcane. However, as was the case with coffee, this change was not uniform and constant. It is possible to notice that this increase in area was concentrated between the years 1993 and 2008, with an increase of 212.6% of the sugarcane planted area. Between 1988 and 1993, the increase was 20.9%; and during the years 2008 and 2013, there was an increase of 8.5%. In the years 2013 to 2018 there was a 4.9% reduction in the planted area. In the first 10 years of analysis (1988 - 1998) the State of Parana had already increased 97.2% of the planted area of sugarcane (Figure 5).

Figure 6 shows the Change Index, indicated by the PCi, for the planted area of sugarcane. We verified that of the 191 municipalities that had some PCi value, 75 had a decrease in the planted sugarcane area. Among these, 24 municipalities completely abandoned sugarcane cultivation and 17 municipalities had a decrease of at least 76% of the area. Despite this, 116 municipalities showed an advance of the crop. A total of 85 of these municipalities showed an increase of at least 100%, reaching up to 88,942.8% of growth in the planted area of sugarcane. Other six municipalities had a growth of at least 76%.

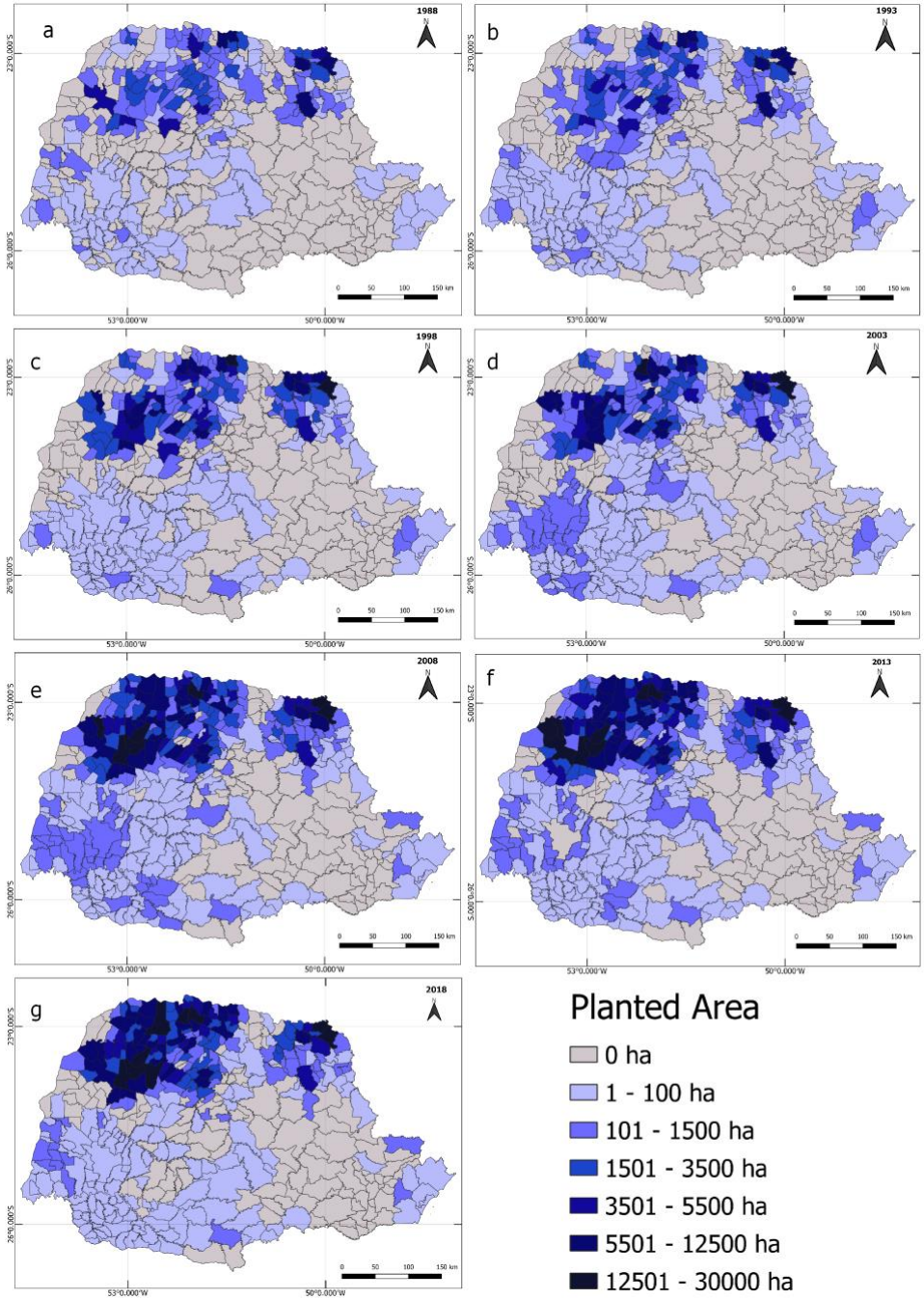


**Figure 4.** Planted area of sugarcane in the State of Parana in the years 1998 (in "a"), 1993 (in "b"), 1998 (in "c"), 2003 (in "d"), 2008 (in "e"), 2013 (in "f"), 2018 (in "g") and percentage of coffee change in the state between 1988 and 2018 (in "h")

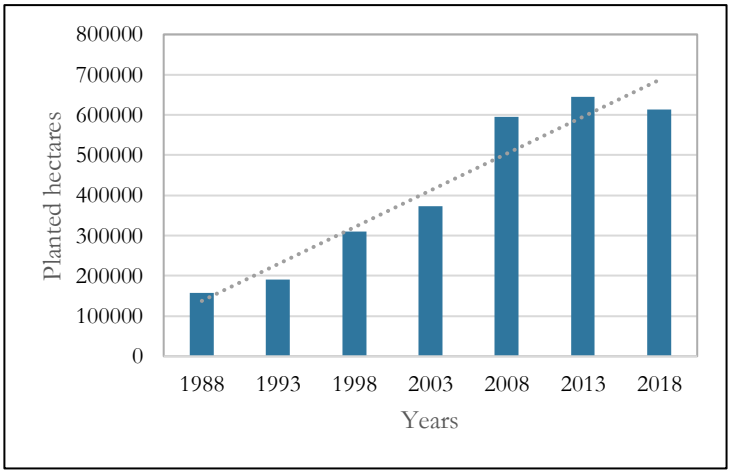


**Figure 5.** Evolution of the planted area of sugarcane in the State of Parana.

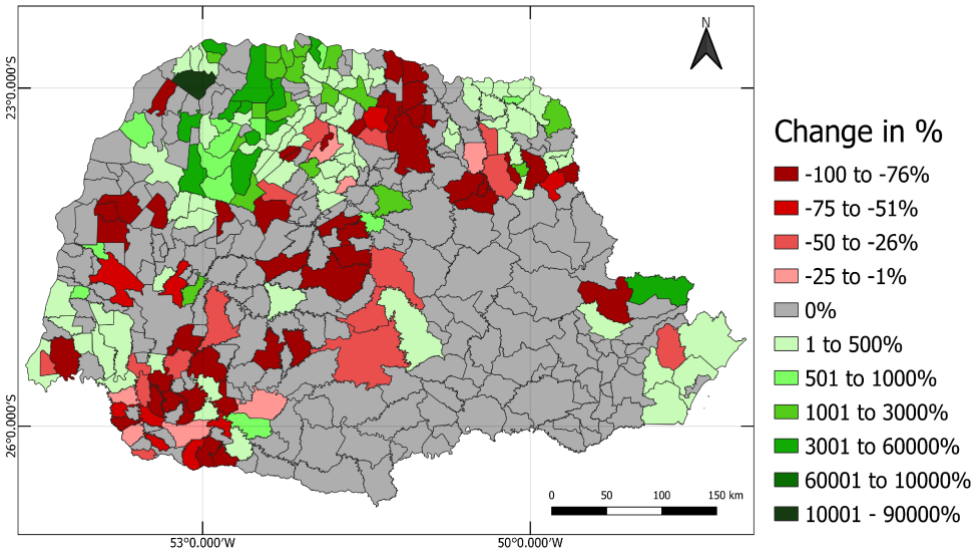


**Figure 6.** Index of Change of the State of Parana for sugarcane crop.

### 3.3. RELATION OF CROP SUBSTITUTION

Considering the data, it was possible to verify which municipalities presented total or partial substitution of coffee by sugarcane, obtaining Figure 7. When analyzing the municipalities that had a decrease in the planted area of coffee and, simultaneously, an increase in sugarcane plantation, we identified that 101 municipalities, from the 399 municipalities of the State of Parana, may have replaced the crops they produced, which represents 25.3% of the municipalities of the state. We observed that most of the substitution occurred in the Northwestern and Northeastern regions of the state, and 16 municipalities are in the region of Indication of Source of the State of Parana, the "Norte Pioneiro Paranaense" (Figure 8). Other nine municipalities are located in the Southwestern region, and municipalities in Southeastern Parana also showed a positive correlation for crop substitution.

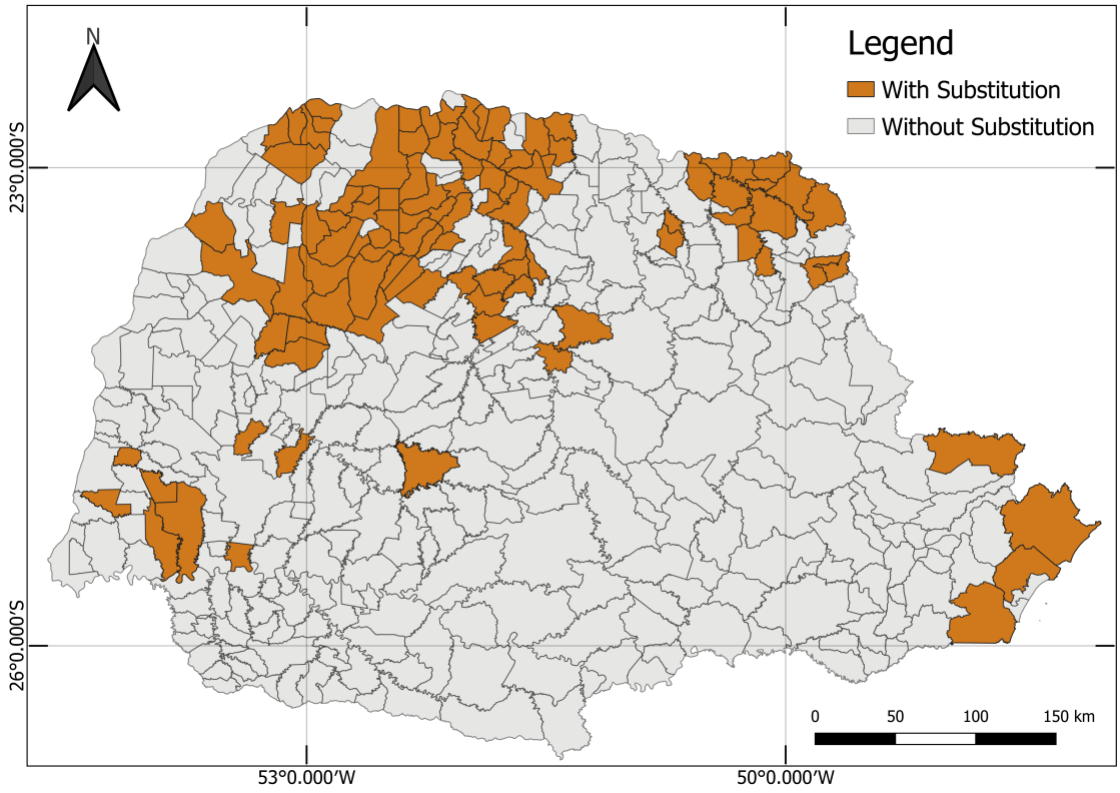


**Figure 7.** Municipalities that decreased coffee area while increased sugarcane area between 1988 and 2018.

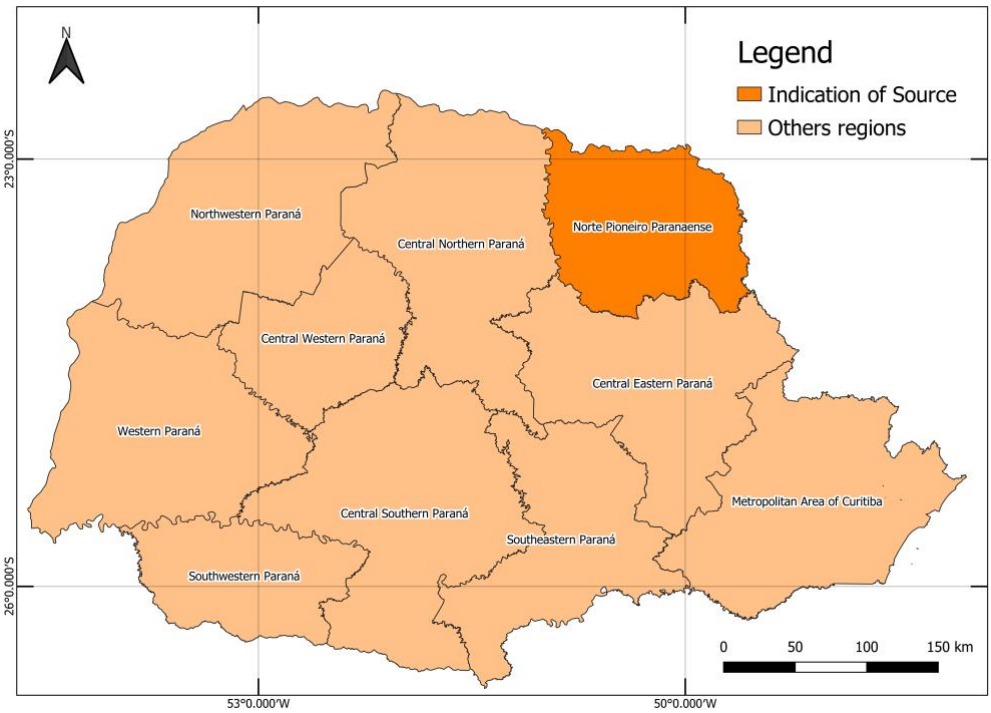


**Figure 8.** Location of the "Norte Pioneiro" (Pioneer North) of Parana state.

### 3.4. Location and altimetry of coffee-producing municipalities

Analyzing the hypsometric map, it was possible to relate producing municipalities with altitudes, thus obtaining Figure 9. It was possible to notice that during the years analyzed, the coffee plantations always remained in the lower regions, mainly between 200 m and 600 m. This was still true in the last year of the analysis period; however, it is possible to notice a concentration of producing area in the North of the state, mainly in the "Norte Pioneiro" (Pioneer North) (Figure 1 "g").

## 4. Discussion

### 4.1. Retraction of the coffee area

The State of Parana, in the 30 years analyzed, had a great decrease in the coffee area. According to Castro et al. (2021), between 1997 and 2016, there was a 65.5% reduction of the planted area, corroborating the data obtained by this study. The authors point to the progress of other crops, such as soybean, corn and wheat, as justifications for this retraction. Other works add the difficulty of crop recovery after the 1975 frost (Robusti et al., 2017) and the fall in export volume during the economic crisis of 2007-2009 (Pereira et al., 2011) as justifications for such change. Likewise, Coltri et al. (2019) noted that, in the State of Sao Paulo, between 1990 and 2013, coffee behaved similarly, with municipalities that completely abandoned the coffee crop, as well as a large decrease of planted area in the remaining municipalities. On the other hand, in the State of Minas Gerais, in the region of Triângulo Mineiro and the Alto Paraíba, Moreira et al. (2015), noted that between the years of 2008 and 2014, the coffee area had an increase of 23.5% in the mesoregion as a whole. However, the authors place the Uberaba microregion as an exception for this expansion, since there was a reduction in the coffee area mainly caused by the expansion of crops like soybeans, corn, and cotton, but mainly sugarcane.

Similar results were found in other parts of the world such as Nicaragua, Honduras, Venezuela and El Salvador, where coffee also showed a reduction in planted area (Imbach et al., 2017; Ovalle-Rivera et al., 2015). On the other hand, the authors state that Mexico, Colombia, Guatemala, Costa Rica, Indonesia and Ethiopia showed a small growth in the coffee area, the main reason being the ability of these countries, compared to those previously mentioned, to move their productions to areas with higher altitudes.

### 4.2. Sugarcane advance and crop replacement

Corroborating the data found, the advance of sugarcane production in Brazil has occurred in several states of the country. Spera et al. (2017) noted the expansion of sugarcane in the State of Goias. The authors state that

sugarcane planted area increased by 490% during the years 2003 and 2013. Likewise, Rudorff et al. (2010), using satellite images, noted an increase of 1.88 million hectares in the State of Sao Paulo during the years 2003 and 2008. The authors state that these expansions were mainly due to the increased demand for ethanol to supply hybrid cars. In the State of Parana, according to Ribeiro et al. (2013), there was an increase in the planted area of sugarcane, mainly between 2006 and 2011. Other countries have also noticed considerable progress in sugarcane. In Africa, Zambia showed a 21.6% advance of sugarcane over other crops, mainly those related to food (German et al., 2020).

The retraction of the coffee planted area can promote the advancement of other cultures, thus causing an effect called "crop substitution". Ronquim and Fonseca (2018) state that sugarcane has been gaining prominence in this substitution in the Brazilian context. According to the authors, the area occupied by sugarcane in the State of Sao Paulo went from 21% to 44% of the state area, and this advance of sugarcane plantations did not occur on native forests, but rather on consolidated agricultural areas. Spera et al. (2017) note that in the State of Goias, sugarcane advanced mainly on soybean crops and pasture areas for cattle. Similar results were obtained by Sparovek et al. (2009), which noted that in the State of Sao Paulo, a significant reduction in pasture occurred following the advance of sugarcane. Likewise, Assunção et al. (2016) noted that, in the State of Mato Grosso do Sul, this substitution occurred mainly after the installation of ethanol distillation plants.

According to Ronquim and Fonseca (2018), farmers replaced coffee crops with sugarcane as it presented a safer and more profitable alternative. Egeskog et al. (2016)still point out that farmers who have changed the use of their properties for sugarcane production will hardly return to the old uses, mainly for two reasons: the high cost for this reversal and the good return on investment that sugarcane has brought. Information such as these strengthens the idea of the progression, and the assured establishment of the sugarcane expansion in Brazil.

### 4.3. Location and altimetry of coffee-producing municipalities

In the analyzed temporal window in Parana, the producing properties are concentrated in the Northeastern regions of the state, a region with Indication of Source called "Norte Pioneiro" (Pioneer North). This corroborates with Castro et al. (2021), which also noted the same concentration. The same was obtained by Coltri et al. (2019), which, in the State of Sao Paulo, observed that coffee areas are concentrated in region producing specific coffees, such as "Alta and Média Mogiana" (in English: "High and Low Mogiana").

In the State of Parana, one can note that the coffee-producing municipalities remained in the lower regions of the state, between 200 and 600m altitudes. The risk of frost may be a possible justification for this concentration in regions of lower altitudes in the State of Parana, since coffee cultivation is not recommended in areas below 500m or higher than 1,200m (Sediyama et al., 2001).

On the other hand, analyzing the trends projected for the global climate, Ovalle-Rivera et al. (2015), state that coffee production is shifting to higher regions due to the rise in temperature caused by climate trends. A study carried out in the State of Minas Gerais, by Barros et al. (2007) observed that, for the municipalities of Aguanil, Boa Esperança, Campo Belo and Cristals, the coffee-producing properties are located mainly between 800 and 900m altitudes. Unlike the rest of the state, the city of Londrina presented 41% of the coffee plantations implanted between 640 and 740m of altitude (Trabaquini et al., 2010).

Malavolta (2000) states that altitude is one of the main points for the quality of the final beverage, as they favor the slower ripening of the grains, which can generate final products of higher quality. As in Brazil, other countries seek better quality of the final beverage, so they adapt the production regions focusing on this. According to Haggar et al. (2013), in Guatemala, there is a large decrease in the planted area of coffee mainly between altitudes of 700 and 1100m. In Nicaragua, by 2050, projections indicate a propensity to move coffee areas to higher altitude regions (Läderach et al., 2017). The authors also mention that producers at lower altitudes will not be able to produce coffee, and thus will be forced to abandon the crop. In agreement, Ovalle-Rivera et al. (2015) state that with the increase in temperature, coffee production will tend to focus on higher altitude areas and countries that do not have apt areas will leave production. This leads producers to tend to make changes regarding use of land, replacing coffee with other crops.

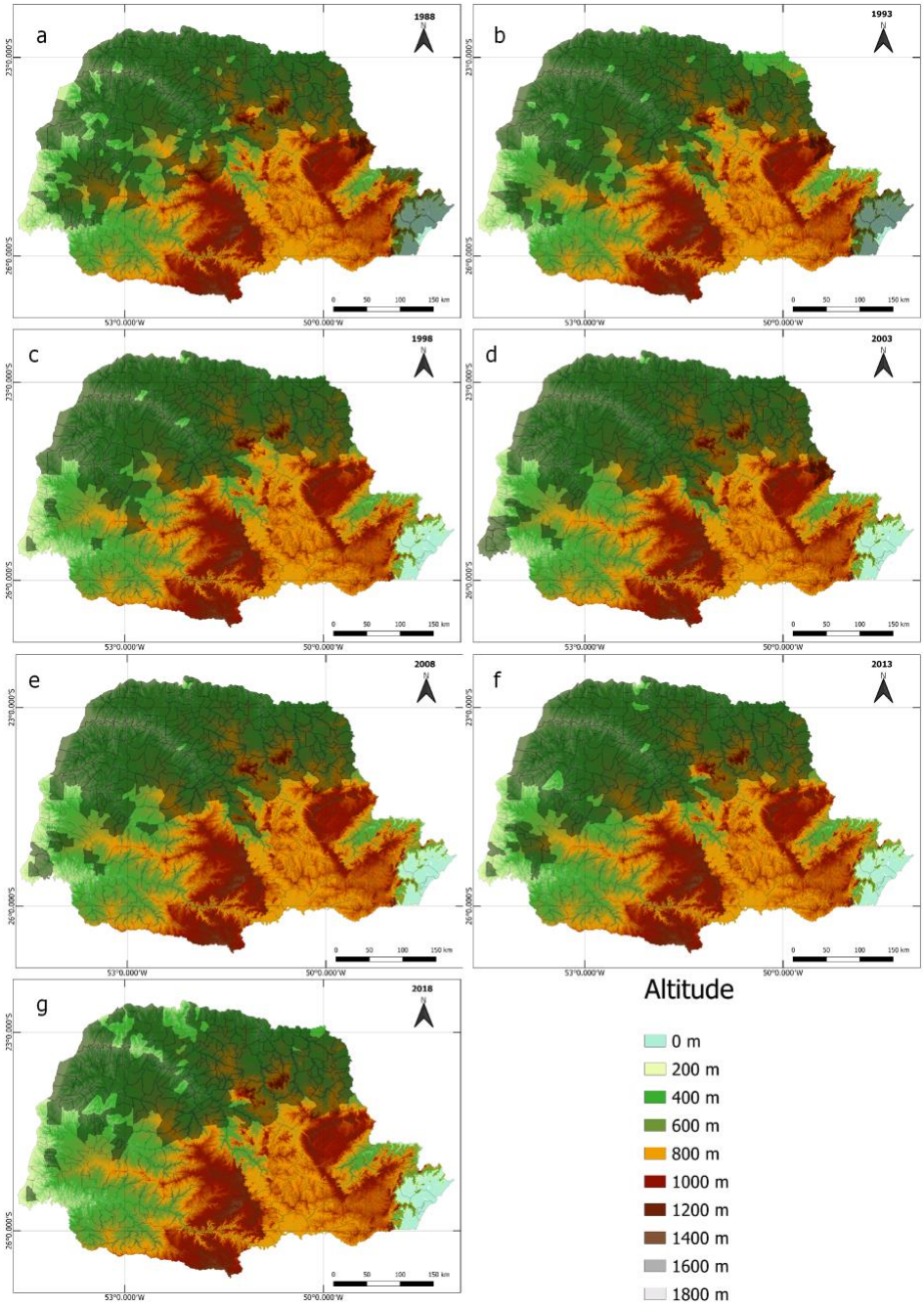


**Figure 9.** Hypsometry of coffee-producing municipalities in 1998 (in "a"), 1993 (in "b"), 1998 (in "c"), 2003 (in "d"), 2008 (in "e"), 2013 (in "f") and 2018 (in "g").

## 5. Conclusion

This work sought to analyze the change in the use and occupation of coffee soil in the State of Parana between 1998 and 2018, comparing it with the change in the use of sugarcane land, with altitude, and regions with indication of source for cultivation in the state. There was a large reduction (about 92.29%) in the coffee area in the 30 years analyzed, mainly between the years 1988 and 1998. At least 40 municipalities have completely abandoned the crop. On the other hand, sugarcane showed a great advance in planted hectares, mainly between 1993 and 2008. In total, there was a 289.87% increase in area.

An interesting point of the analysis is that the concentration of coffee occurred mainly in the North of the state and that the advance of sugarcane occurred in this same region. With this, it was possible to state the hypothesis that many producers chose to replace coffee with sugarcane. A total of 101 municipalities (i.e., approximately 25% of the municipalities in the state) made this change in land use.

The remaining coffee was still maintained in the region to the north of the State of Parana, confirming the hypothesis that it would concentrate in the region with indication of source, the "Norte Pioneiro Paranaense". However, with the altimetry of the municipalities, we noted that coffee was concentrated in the lower regions of the state, even though better beverages are produced at higher altitudes. The risk of frosts, which in the past has already caused damage to producers, could be a justification for this movement.

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## 6. References

Alfonsi, W. M. V., Coltri, P. P., Zullo Júnior, J., Patrício, F. R. A., & Alfonsi, E. L. (2019). Período de incubação da ferrugem do cafeeiro. *Summa Phytopathologica*, *45*(2), 134–140. https://doi.org/10.1590/0100-5405/187216

Assunção, J., Pietracci, B., & Souza, P. (2016). Fueling Development: Sugarcane Expansion Impacts in Brazil. *Clim.Police Initiat.*, 1–56. https://climatepolicyinitiative.org/wp-content/uploads/2016/07/Paper_Fueling_Development_Sugarcane_Expansion_Impacts_in_Brazil_Working_Paper_CPI.pdf.pdf

Barros, M. A., Moreira, M. A., & Rudorff, B. F. T. (2007). DADOS INTERFEROMÉTRICOS PARA MODELAGEM TOPOGRÁFICA E CARACTERIZAÇÃO AMBIENTAL DO CAFÉ EM ESCALA MUNICIPAL. *Sociedade & Natureza*, *19*(2), 33–50. https://doi.org/10.1590/S1982-45132007000200003

Berry, J. K. Cartographic Modeling: The analytical capabilities of GIS. Environmental Modeling with GIS. Oxford University Press, p. 488, 1993.

Bongase, E. D. (2017). Impacts of climate change on global coffee production industry: Review. *African Journal of Agricultural Research*, *12*(19), 1607–1611. https://doi.org/10.5897/ajar2017.12147

BRASIL. Lei 9.279, de 14 de maio de 1996. Regula os direitos e obrigações relativos à propriedades insdustrial. Disponível em: <http://www.planalto.gov.br/ccivil_03/leis/l9279.htm>. Acesso em: 03 de abril 2021.

Castro, G. . H. L., Leocádio, A. L. M., Ribeiro, M. R., & Telles, T. S. (2021). ORGANIZAÇÃO ESPAÇO-TEMPORAL DA PRODUÇÃO DO CAFÉ NO PARANÁ. *Informe GEPEC*, *25*, 109–132.

Coltri, P. P., Lima, P. R., Koga-Vicente, A., & Gonçalves, R. R. D. V. (2019). Coffee land cover changes analyses: A study case in são paulo state. *Coffee Science*, *14*(2), 131–137. https://doi.org/10.25186/cs.v14i2.1540

Davis, A. P., Gole, T. W., Baena, S., & Moat, J. (2012). The Impact of Climate Change on Indigenous Arabica Coffee (Coffea arabica): Predicting Future Trends and Identifying Priorities. *PLoS ONE*, *7*(11), 10–14. https://doi.org/10.1371/journal.pone.0047981

Camargo, M. B. P. (2010). The impact of climatic variability and climate change on Arabic coffee crop in Brazil. *Bragantia*, *69*(1), 239–247. https://doi.org/10.1590/s0006-87052010000100030

Egeskog, A., Barretto, A., Berndes, G., Freitas, F., Holmén, M., Sparovek, G., & Torén, J. (2016). Actions and opinions of Brazilian farmers who shift to sugarcane-an interview-based assessment with discussion of implications for land-use change. *Land Use Policy*, *57*, 594–604. https://doi.org/10.1016/j.landusepol.2016.06.022

German, L. A., Hepinstall-Cymerman, J., Biggs, T., Parker, L., & Salinas, M. (2020). The environmental effects of sugarcane expansion: A case study of changes in land and water use in southern Africa. In *Applied Geography* (Vol. 121). https://doi.org/10.1016/j.apgeog.2020.102240

Giesbrecht, H. O., & Minas, R. B. A. (2016). *Indicações Geográficas Brasileiras.*

Haggar, J., Medina, B., Aguilar, R. M., & Munoz, C. (2013). Land use change on coffee farms in southern guatemala and its environmental consequences. *Environmental Management*, *51*(4), 811–823. https://doi.org/10.1007/s00267-013-0019-7

Imbach, P., Fung, E., Hannah, L., Navarro-Racines, C. E., Roubik, D. W., Ricketts, T. H., Harvey, C. A., Donatti, C. I., Läderach, P., Locatelli, B., & Roehrdanz, P. R. (2017). Coupling of pollination services and coffee suitability under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(39), 10438–10442. https://doi.org/10.1073/pnas.1617940114

Iscaro, J. (2014). The Impact of Climate Change on Coffee Production in Colombia and Ethiopia. *Global Majority E-Journal*, *5*(1), 33–43.

Läderach, P., Ramirez–Villegas, J., Navarro-Racines, C., Zelaya, C., Martinez–Valle, A., & Jarvis, A. (2017). Climate change adaptation of coffee production in space and time. *Climatic Change*, *141*(1), 47–62. https://doi.org/10.1007/s10584-016-1788-9

Malavolta, E. História do café no Brasil: agronomia, agricultura e comercialização. São Paulo: Agronômica Ceres, p. 464, 2000.

Martinelli, L. A., & Filoso, S. (2008). Expansion of sugarcane ethanol production in Brazil: Environmental and social challenges. *Ecological Applications*, *18*(4), 885–898. https://doi.org/10.1890/07-1813.1

Moreira, M. A., Araujo, D. M., Saito, N. S., Martini, D. Z., Marujo, R. de F. B., & Faria, V. G. C. de. (2015). Uso de dados de sensoriamento remoto para análise multitemporal da cafeicultura no Triangulo Mineiro/Alto Paranaíba nos anos de 2008 e 2014. *Simpósio Brasileiro de Sensoriamento Remoto*, *17*, 6381–6388.

Mulianga, B., Bégué, A., Clouvel, P., & Todoroff, P. (2015). Mapping cropping practices of a sugarcane-based cropping system in Kenya using remote sensing. *Remote Sensing*, *7*(11), 14428–14444. https://doi.org/10.3390/rs71114428

Oliveira, M. E. D., Vaughan, B. E., & Rykiel, E. J. (2005). Ethanol as fuel: Energy, carbon dioxide balances, and ecological footprint. *BioScience*, *55*(7), 593–602. https://doi.org/10.1641/0006-3568(2005)055[0593:EAFECD]2.0.CO;2

Ovalle-Rivera, O., Läderach, P., Bunn, C., Obersteiner, M., & Schroth, G. (2015). Projected shifts in Coffea arabica suitability among major global producing regions due to climate change. *PLoS ONE*, *10*(4), 1–13. https://doi.org/10.1371/journal.pone.0124155

Pereira, V. da F., Campos, A. C., Braga, M. J., & Mendonça, T. G. (2011). A CRISE ECONÔMICA MUNDIAL DE 2007 A 2009 E O SETOR EXPORTADOR DE CAFÉ NO BRASIL: ANÁLISE DAS PERDAS. *Revista de Economia e Agronegócio*, *9*(2), 187–208. https://doi.org/10.25070/rea.v9i2.183

Ribeiro, V. H., Gonçalves Junior, F. de A., & Paiva, R. G. (2013). TRANSFORMAÇÕES DA PAISAGEM RURAL DA MICRORREGIÃO DE PARANAVAÍ-PR E A EXPANSÃO DA CANA-DE-AÇÚCAR NOS MUNICÍPIOS DE TAMBOARA E ITAÚNA DO SUL DE 1970- 2012. *Percurso*, *5*(1), 55–86.

Robusti, E. A., Zapparoli, I. D., & Santoro, P. H. (2017). Café arborizado no estado do paraná, Brazil: Indicadores financeiros e interferências ambientais, 2012-2014. *Agroalimentaria*, *23*(44), 79–91.

Ronquim, C. C. ., & Fonseca, M. F. (2018). Avanço das áreas de cana-de-açúcar e alterações em áreas de agropecuária no interior paulista. *CAMPINAS, SP: Embrapa Territorial, (Embrapa Territorial. Documentos, 123).*, 48.

Rudorff, B. F. T., de Aguiar, D. A., da Silva, W. F., Sugawara, L. M., Adami, M., & Moreira, M. A. (2010). Studies on the rapid expansion of sugarcane for ethanol production in São Paulo state (Brazil) using Landsat data. *Remote Sensing*, *2*(4), 1057–1076. https://doi.org/10.3390/rs2041057

Sediyama, G. C., César, J., Melo, F. De, Rosa, A., Ribeiro, A., Costa, M. H., & Hamakawa, P. J. (2001). Zoneamento agroclimático do cafeeiro ( Coffea arabica L .) para o estado de Minas Gerais. *Revista Brasileira de Agrometeorologia*, *9*(3), 501–509.

Sparovek, G., Barretto, A., Berndes, G., Martins, S., & Maule, R. (2009). Environmental, land-use and economic implications of Brazilian sugarcane expansion 1996-2006. *Mitigation and Adaptation Strategies for Global Change*, *14*(3), 285–298. https://doi.org/10.1007/s11027-008-9164-3

Spera, S., VanWey, L., & Mustard, J. (2017). The drivers of sugarcane expansion in Goiás, Brazil. *Land Use Policy*, *66*(May), 111–119. https://doi.org/10.1016/j.landusepol.2017.03.037

Trabaquini, K., Miglioranza, E., França, V., & Pereira Neto, O. C. (2010). USO DA GEOTECNOLOGIA PARA CARACTERIZAR OS CAFEZAIS NO MUNICÍPIO DE LONDRINA-PR, EM RELAÇÃO À ALTIMETRIA, DECLIVIDADE E TIPO DE SOLO. *Journal of Food System Research*, *30*(6), 1136–1147. https://doi.org/10.5874/jfsr.2.2_54

Zullo, J., Pereira, V. R., & Koga-Vicente, A. (2018). Sugar-energy sector vulnerability under CMIP5 projections in the Brazilian central-southern macro-region. *Climatic Change*, *149*(3-4), 489-502. https://doi.org/10.1007/s10584-018-2249-4