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Zoning of coffee growing areas suitable for agricultural mechanization in the State of Espírito Santo

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ABSTRACT
The State of Espírito Santo has national prominence in terms of coffee production. However, the slope is a limiting factor for the implementation of mechanization. In view of this, the objective was to carry out, based on the slope, the zoning of coffee growing areas suitable for agricultural mechanization in the State of Espírito Santo. The planialtimetric survey used was the Geobases with a resolution of 5m, with the aid of geoprocessing software, the Digital Terrain Model (DTM) was generated and, subsequently, the slope of the coffee growing areas, which were classified according to the mechanization potential of the land: Extremely Suitable (0 - 5%), Very Suitable (5.1 - 10%), Suitable (10.1 - 15%), Moderately Fit (15.1 - 20%) and Not Recommended (> 20%). The state has 428,482.6 thousand hectares of Coffea canephora and Coffea arabica. Being 21.6%; 11.3% and 11.2% with extremely apt, very apt and apt mechanization potential. In addition, 10.7% of the cultivated area was classified as moderately suitable and 45.3% as an area not recommended for mechanized activities. It is also noteworthy that the municipalities with high production of Coffea canephora have the crops with greater aptitude for mechanization when compared to the municipalities that have high production Coffea arabica crops.

Keywords: Coffee growing, Slope, Clinographic map, Slope classes, Mechanization potential.

1 INTRODUCTION

The narrative of coffee culture is linked to Brazil's economic and geopolitical development (FREDERICO, 2017). Today, the largest coffee producers are: Minas Gerais with a production of 21.96 million bags and Espírito Santo with a production of 16.72 million bags (CONAB, 2022).

The introduction of coffee cultivation in Espírito Santo took place in 1912 by the then Governor Jerônimo Monteiro. However, it was only in 1971 that cultivation on a commercial basis began (SILVA et al., 2017). Today it is an important activity for more than 130 thousand farming families (INCAPER, 2017). In 2022, the State contributed about 68% of the national production of conilon coffee (CONAB, 2022), and all or most of the production is concentrated in places with altitudes of up to 500 meters (INCAPER, 2017). On the other hand, Arabica coffee is considered the most important economic

activity for farmers in regions with altitudes above 500 meters, being the main agricultural product for about 80% of the rural properties in Espírito Santo located in these regions; in 2022, about 4.4 million bags of Arabica coffee were produced (CONAB, 2022).

As in other producing regions, coffee farming in Espírito Santo has been facing a crisis in the supply of labor. The migration of many rural families to urban centers in search of increased income and financial stability, as well as better access to health and quality education, has caused a shortage of available labor in the countryside. This low supply ends up burdening production costs and limiting the exploitation of the crop in the period of greatest demand, the harvest (SOUZA, et al., 2017).

The complete replacement of manual harvesting by mechanization makes it possible to reduce the cost of harvesting by up to 60% (SANTINATO et al., 2015; LANNA and REIS, 2012). In mechanized harvesting, harvesters simultaneously carry out the operations of harvesting, collecting, shaking, and bagging or storing coffee beans. Semi-mechanized harvesting, on the other hand, relies on the association of manual labor with agricultural machinery to carry out the harvest, being a system with a high growth trend among this class of producers. However, for both systems, the use of machinery is limited by topography (REZENDE et al., 2013).

One of the main limitations for the increase in mechanized areas has been the difficulty in developing machines capable of being operated safely in steeper slope conditions, such as coffee cultivation in mountainous areas (OLIVEIRA et al., 2013). Traditional mechanization methods can only be applied to land with a slope of up to 20% (SILVA et al., 2001).

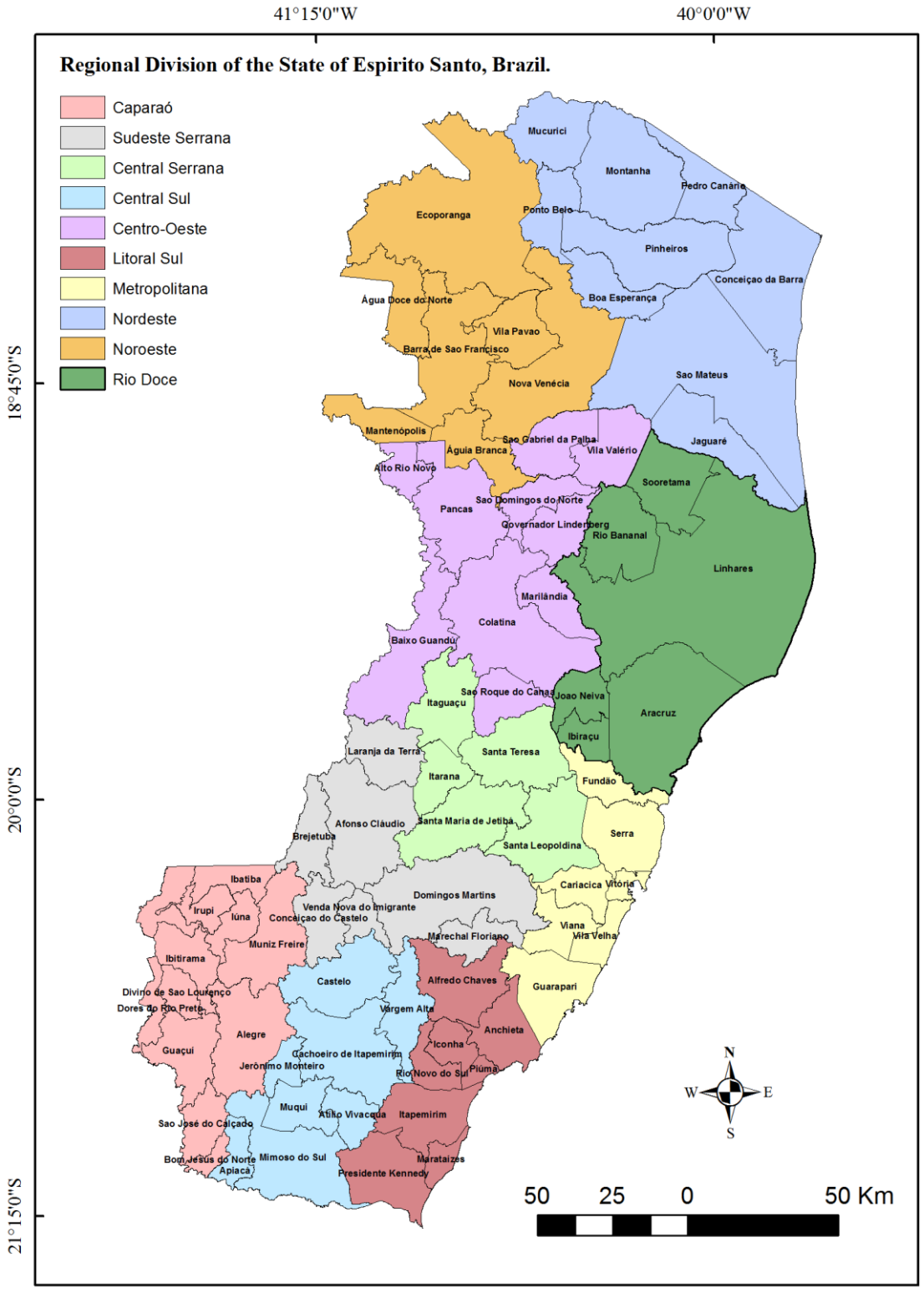
The slope of the land is understood as a geomorphological variable that can limit the use of a given soil for agriculture, a fact described in the Brazilian legislation itself (MOREIRA and VALERIANO, 2013), therefore, different levels of slope are directly related to the permissible classes of land use. This can be estimated through contour lines or elevation points, field clinometer and through the derivation of Digital Elevation Models (DEM) (VALERIANO and ALBUQUERQUE, 2010).

From data provided by different sources and implementation of different methodologies, it is possible to map the slope for the most distinct applications, including agricultural aptitude and the potential for mechanization of the area, which will help the decision-making process by the producer in terms of reducing production costs and improving coffee quality. As it was noted the existence of a gap in research that addresses the ability of mechanization of the areas as a function of the slope, this fact highlights the relevance of the present study for coffee growing in Espírito Santo. In view of the above, the objective was to carry out, based on the slope, the zoning of coffee growing areas suitable for agricultural mechanization in the State of Espírito Santo.

2 MATERIAL AND METHODS

Espírito Santo is a state located in the southeastern region of Brazil with an area of 46,077 km², divided into 10 micro-regions and 78 municipalities (Figure 1), with an estimated population of 4.179 million (IBGE, 2023).

Figure 1 – Visualization of the State of Espírito Santo, highlighting the micro-regons and their respective municipalities. Source: Geobases, modified by the author.



In the state, the climate classified by Köppen as Aw (ALVARES et al. 2013) predominates, humid tropical, where there is a greater volume of precipitation in the summer and less in the winter. It has average annual air temperatures between 22° and 24°C and precipitation of more than 1,400 mm per year. As for the relief, about 40% of the territorial area is distributed along the coast as a coastal plain or coastal lowlands. In the interior of the state, the presence of a plateau characterizes the mountainous region, where altitudes above 2,000 meters are found (Espírito Santo, 2016).

The data used in the survey were obtained from the Integrated System of Georeferenced Bases of the State of Espírito Santo - GEOBASES, which is the Spatial Data Infrastructure (IDE) of the State. Geobases has very high spatial resolution images, contour lines with an equidistance of five meters, land use and land cover maps, among other data; which are the results of an aerial survey carried out in Espírito Santo between 2012 and 2015 (GEOBASES, 2023).

The survey of the potential for mechanization of the coffee growing areas of the State of Espírito Santo was developed according to the following methodological steps:

- Obtaining the planialtimetric survey of the entire State of Espírito Santo in the Geobases database, by downloading the contour lines.
- Obtaining the map of land use and land cover areas by downloading it from the Geobases database. From this mapping, the photointerpretation of the soil areas that are in use with the coffee crop was carried out.
- Modeling the data in ArcGIS 10® software, generating an MDT. The Digital Elevation Model (DEM) or numerical terrain model (MNT) has several applications, including the elaboration of slope maps (CARVALHO and BAYER, 2008).
- Generation of the MDT: the contour lines obtained with the planialtimetric survey were used. Within the ArcGIS 10 program, in the ArcToolbox, the Spatial Analyst Tools and the Topo to Raster interpolator were used, with a resolution of 20® meters being adopted. The MDT generated was limited to coffee areas.
- Slope generation. Calculated directly from the Digital Terrain Model, the slope tool of ArcGIS 10® was used to obtain the slope. This tool calculates the maximum rate of change, from eight cells adjacent to a central cell. The percentage slope is calculated by the change in height (dZ), divided by the change in distance (dX) multiplied by 100 [Slope % = (dZ/dX)*100] (HOFIG and ARAÚJO JUNIOR, 2015). The slope classes were used to infer the relief of the coffee areas, according to the correlation of the slope classes and relief classes presented by Rezende et al. (2013), Table 1.

Table 1 - Correlation between slope classes and relief classes

Slope classes (%)	Relief classes
0 - 3	Flat
3 - 12	Soft wavy
12 - 22	Wavy
22 - 45	Strong wavy
45 - 75	Mountainous
> 75	Scarp

- Classification of slope levels according to parameters adopted for the implementation of mechanization; From the calculation of slope made with the slope tool, the classification of the slope classes of the coffee areas was carried out, which were distributed according to the potential for mechanization, as shown in Table 2.

Table 2 - Slope classes in relation to mechanization

Slope classes (%)	Suitability of land for mechanization
0 - 5	Extremely suitable
5 - 10	Very suitable
10 - 15	Suitable
15 - 20	Moderately suitable
> 20	Not recommended

Source: Hofig and Araújo Junior (2015).

3 RESULTS AND DISCUSSION

The methodology approached allowed the identification and quantification, according to their slope, of the coffee growing areas along the entire territorial extension of the State of Espírito Santo.

Figure 2 shows the map of the areas occupied by the cultivation of Coffea arabica and C. canephora in the State of Espírito Santo; Distributed throughout the entire territorial extension, coffee plantations add up to about 428,482.6 hectares.

Analyzing the slicing adopted for the altimetry values in the coffee plantations, illustrated in the thematic map of the altitude classes (Figure 3), a great variation in altitude is observed throughout the areas of coffee plantations in the State of Espírito Santo. There is an occurrence of coffee plantations at altitudes above 1400 meters above sea level. Gair (2012) states in his study that coffees produced from coffee trees located at altitudes above 900 meters have better beverage quality.

The slope classes expressed as percentages are illustrated in Figure 4. Based on the correlation between slope classes and relief classes, according to Rezende et al. (2013), we can infer that the relief of coffee plantations in Espírito Santo varies in general, from flat to strongly undulating, in the latter case preventing the entry of agricultural machinery into the cultivated area. According to the legislation in force in Espírito Santo, it is prohibited, throughout the state territory, the use of soil preparation methods for agricultural, livestock and forestry purposes that adopt the movement of mechanical or animal traction equipment, in the direction of the topographic slope, in cleaning, plowing, harrowing and similar operations, in areas whose slope is equal to or greater than 20%. It is the responsibility of

SEAG – State Department of Agriculture, to coordinate the policy for the conservation of agricultural soil; IDAF - Institute of Agricultural and Forestry Defense of Espírito Santo, the inspection of compliance with legal standards, including this law; and INCAPER - Capixaba Institute of Research, Technical Assistance and Rural Extension, the technical guidance to rural producers regarding soil preparation and management methods (Espírito Santo, 2001).

Figure 2 - Areas under cultivation of Coffea canephora and Coffea arabica in the State of Espírito Santo.

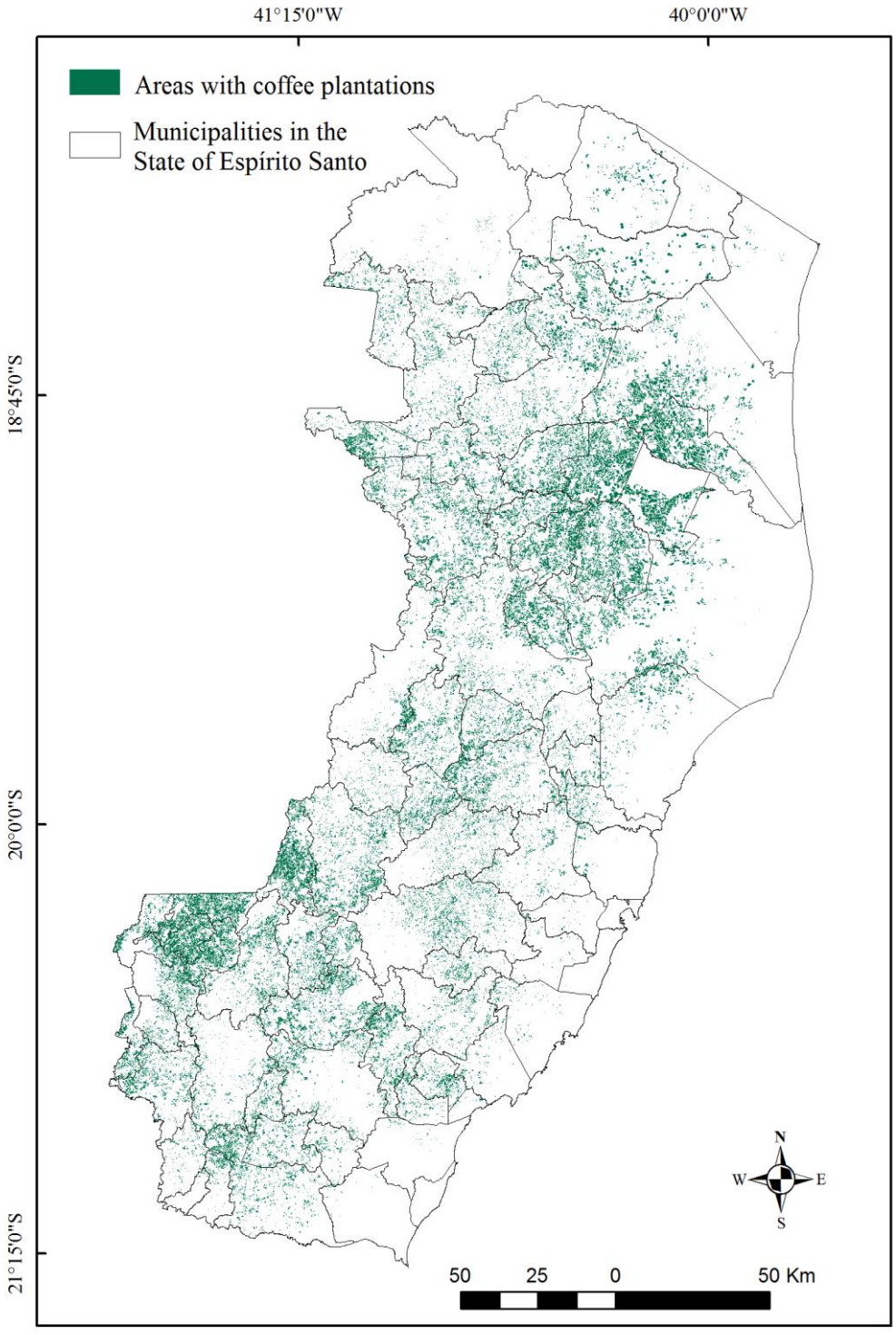


Figure 3 - Altitude classes, in meters, for the coffee-growing areas of Espírito Santo.

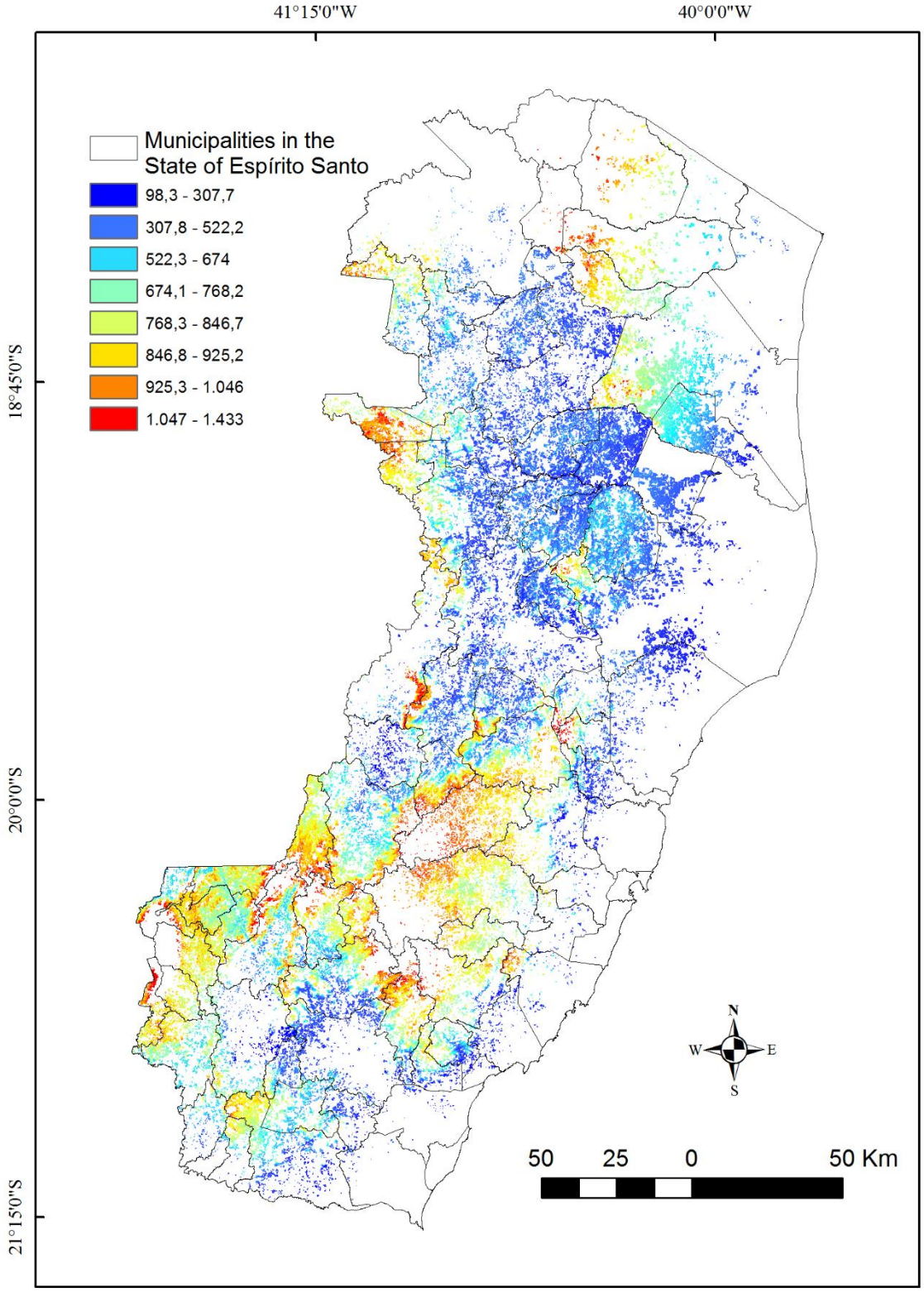
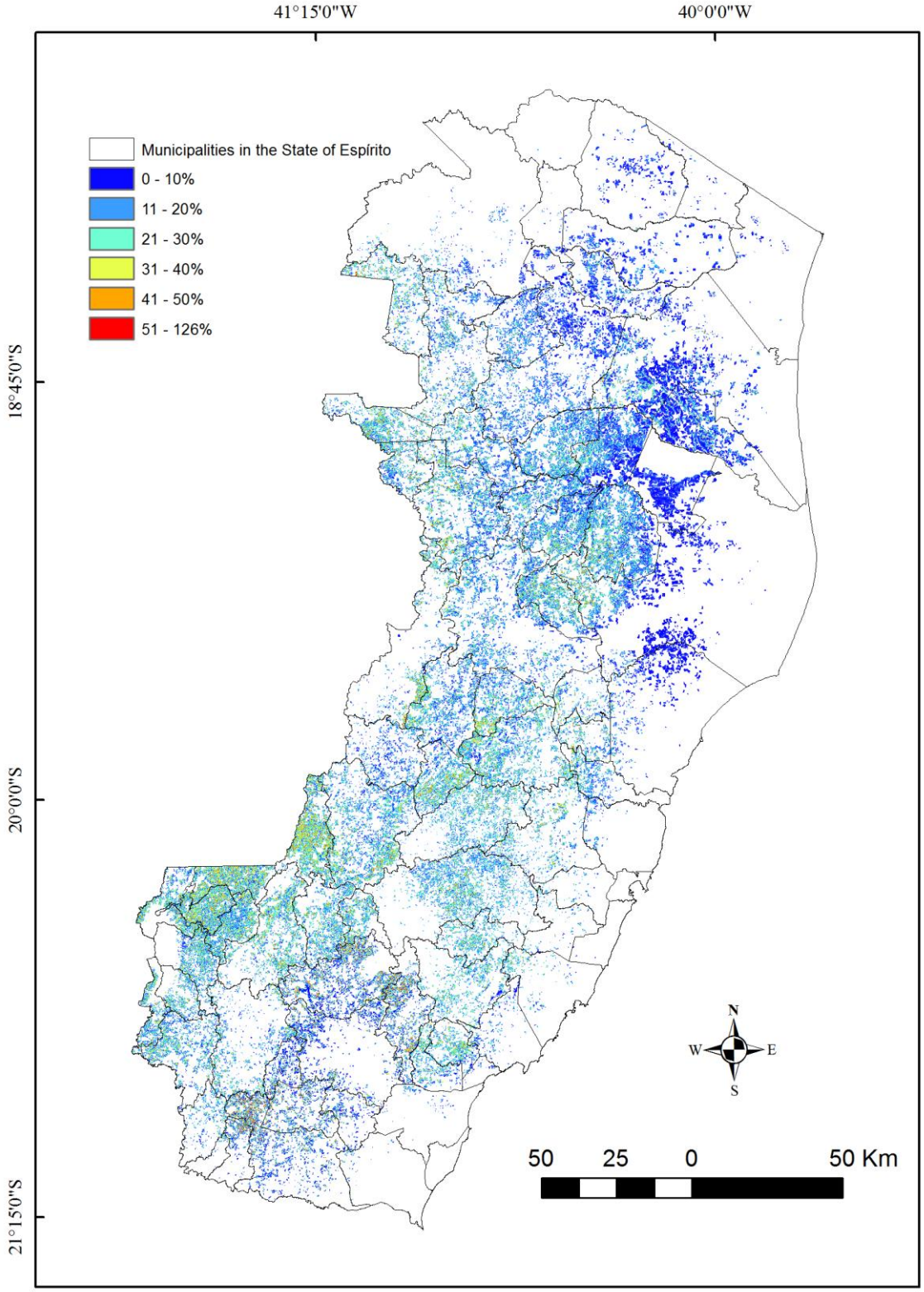


Figure 4 – Slope classes in percentage (%) for coffee growing areas in the State of Espírito Santo.



From the 428,482.6 hectares planted with coffee in Espírito Santo, 21.6% (92,415.3 ha) was obtained; 11.3% (48,444.7 ha) and 11.2% (47,890.4 ha) of an area with extremely suitable, very suitable and suitable mechanization potential, respectively, totaling 44.1% (Table 3). In addition, 10.7% (45,673.3 ha) of the cultivated area falls into the moderately fit class and another 45.3%

(194,058.8 ha) have a slope greater than 20% and, for legal reasons related to soil conservation, operational efficiency or greater propensity to accidents, mechanized activities are not recommended (OLIVEIRA et al., 2013). It is noteworthy that, in the present study, the slope is the basis for the criterion adopted for the establishment of the classes of aptitude for mechanization. To complement the study, it is essential to evaluate other criteria for decision-making; in this case, the type and physical conditions of the soil, the spacing between rows, the width of the traffic and manoeuvring carriers, the existence of obstacles to the passage of machines between rows, the size of the rows, the height of the floor (REZENDE et al., 2013) and some other aspects should be taken into account. which are part of the line of recommendation for when it is desirable to mechanize crops in the area.

Table 3 - Slope classes and suitability for mechanization of coffee growing areas in the State of Espírito Santo.

Slope classes (%)	Suitability of land for mechanization	Area (ha)	Percentage (%)
0 - 5	Extremely suitable	92.415,3	21,6
5 -10	Very suitable	48.444,7	11,3
10 - 15	Suitable	47.890,4	11,2
15 - 20	Moderately suitable	45.673,3	10,7
> 20%	Not recommended	194.058,8	45,3
Total		428.482,6	100

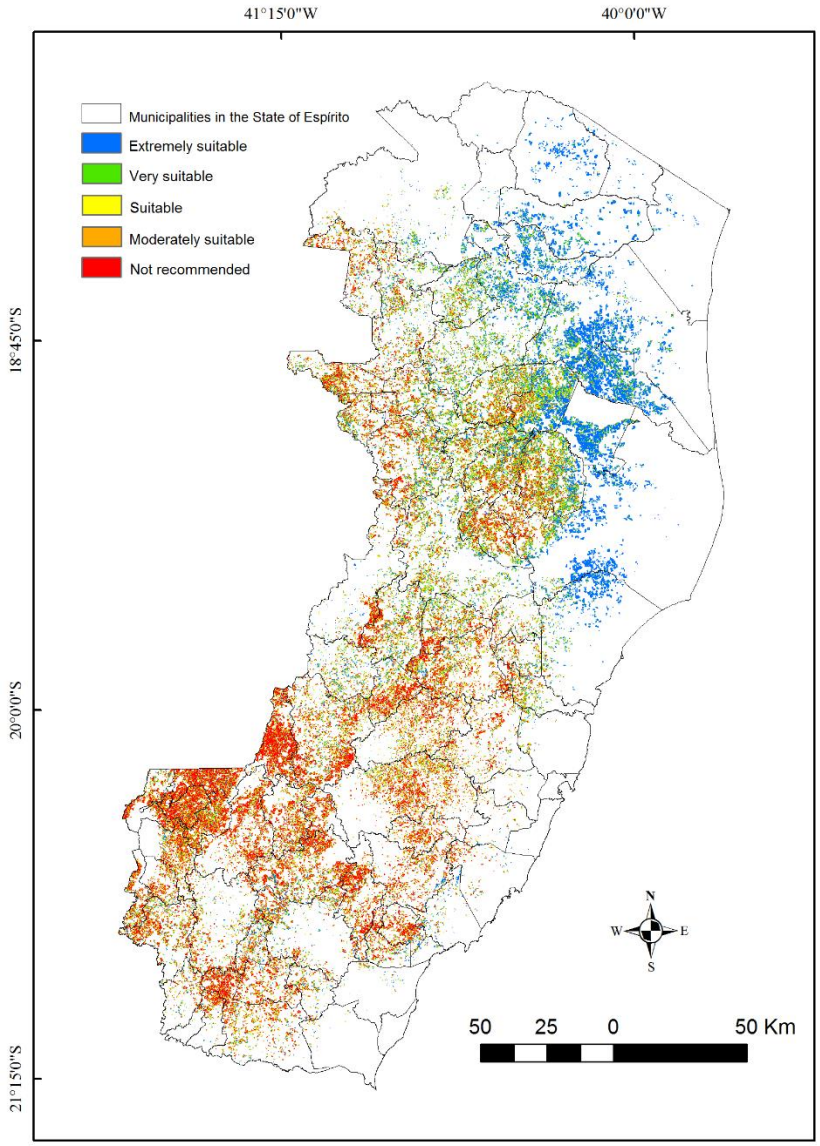
Figure 5 shows the suitability of the areas for mechanization. There are 188,750.46 hectares of areas suitable for mechanization and 239,732.13 hectares that are not recommended for mechanization. In addition, it is observed that there is a predominance of cultivated areas suitable for mechanization in the northern portion of the state.

In a study aimed at qualifying the mechanization potential of coffee plantations and their expansion potential in the State of Espírito Santo, Souza et al. (2019) used images from the Shuttle Radar Topographic Mission (SRTM), with a spatial resolution of 90 m, as a basis. As a result, they obtained that, out of a total of 432 thousand hectares of areas planted with coffee, the areas that were extremely suitable, very suitable and suitable for mechanization represented a total of 22.4%; 14.9% and 13.9%, respectively, and 20.5% of the area that does not have a recommendation for mechanization because it is in the slope range between 20 and 30%. In relation to the present study, the differences between the results can be explained, in large part, by the difference in the spatial resolution of the sources used.

The categories of medium and strong natural fragility of the relief - 12 to 30% of slope, present obstacles to agricultural mechanization (COLAVITE and PASSOS, 2012), limiting soil preparation and management activities. Tavares (2016) concluded in his work that in areas with a slope of 0 to 15%, the collection of coffee carried out in a mechanized way presents the same performance, while for slopes greater than 15% there is a reduction in the operational capacity of harvesters; And in terms of operational efficiency, manoeuvring and operating times are affected by slopes. For maneuver times,

in areas from 10.1 to 15.0% and from 15.1 to 20.0% of slope, there was an increase of 37% and 106%, respectively, in relation to flat areas (0.0 to 5.0%). On the other hand, the time spent in collection operations in areas of 15.1 to 20.0% slope increased by 1 hour and 29 min ha-1 (111%) when compared to the same route in a flat place (0 to 5%). This is because on steeper slopes, there are points of greater inclination that force the operator to change gears at all times to reduce the speed and the risks of tipping over the collector. Therefore, the operational efficiency is higher on flat slope compared to undulating slope and as a result of this the production yield decreases with the increase in the percentage of slope of the relief (MIYAJIMA et al., 2016; SIMÕES and FENNER, 2010). However, it is worth mentioning that recent improvements in harvesters favor their performance on higher slopes, Oliveira et al. (2013) demonstrated in their study that, in terms of percentage, a harvester with an approximate weight of 1470 kg can travel on a slope of up to 46%, without even using the transverse leveling system.

Figure 5 – Visualization of the aptitude classes of coffee areas for agricultural mechanization in the State of Espírito Santo.



The municipalities in the north of the state, in addition to being responsible for a significant volume of Coffea canephora production, have great aptitude for mechanization (Figure 6). With the exception of Colatina and Governador Lindenberg, which have potential for mechanization in only 50% of their coffee plantations, all other municipalities have a predominance of relief that allows machinery operations (Figure 7). This is a very positive factor and indicator of the high coffee production rates in these municipalities.

Figure 6 – Visualization of the municipalities in the northern portion of Espírito Santo that stand out in coffee cultivation and the classification of the cultivated areas of these municipalities according to their suitability for mechanization.

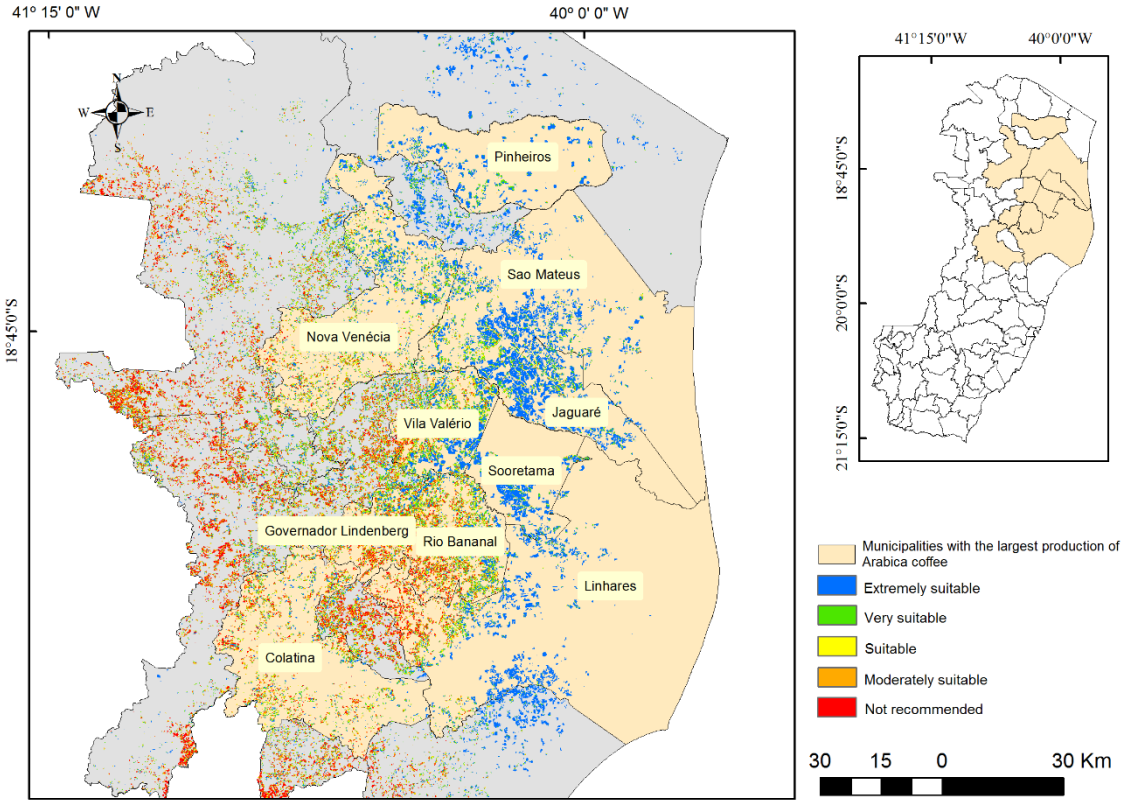
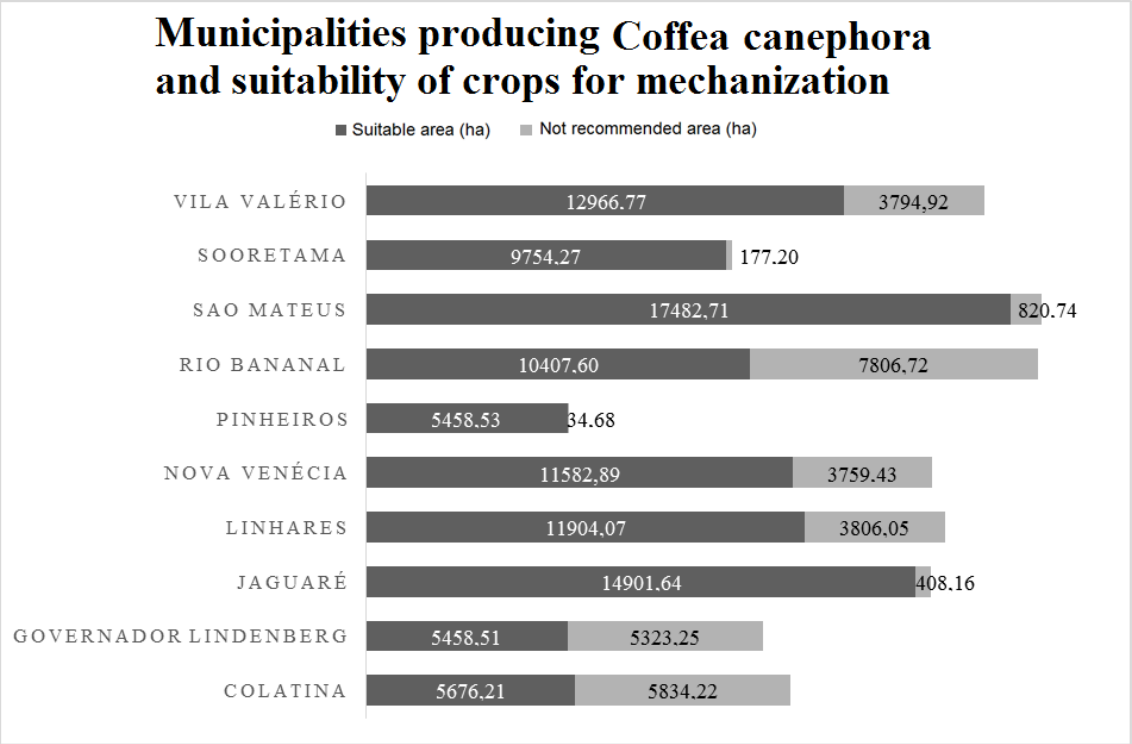
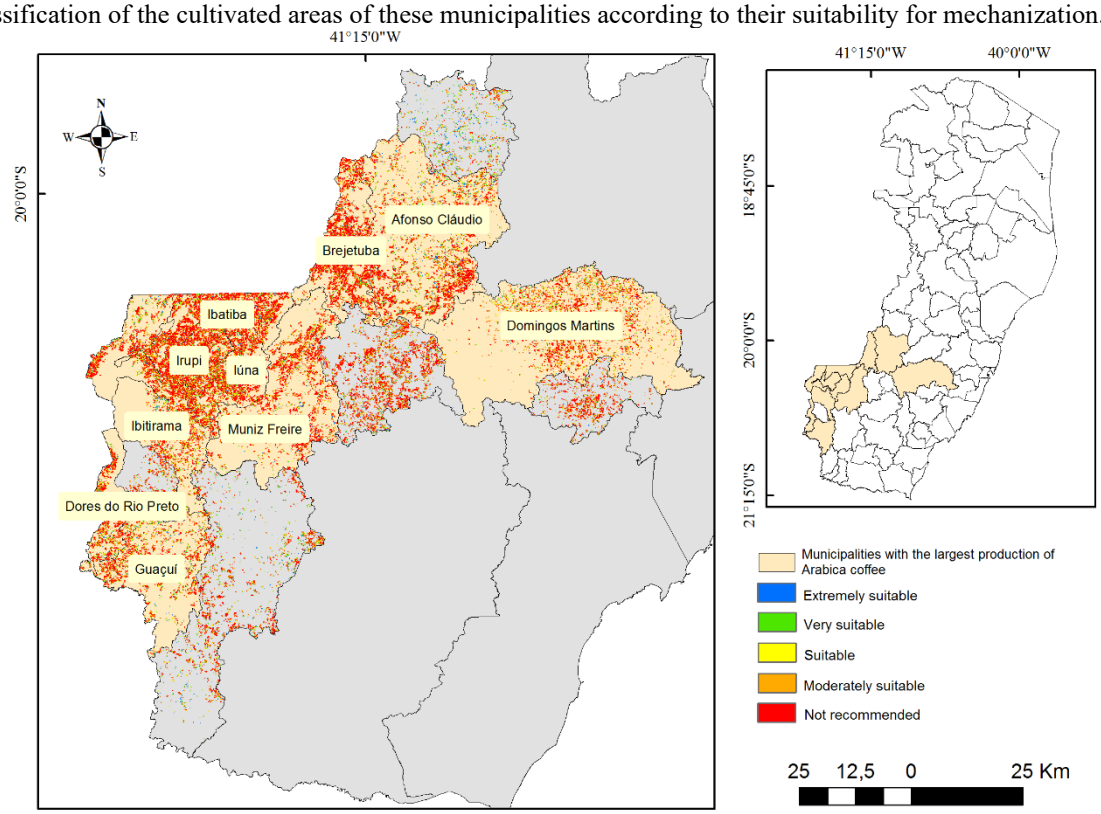


Figure 7 - Graph of the ten municipalities with the highest production of Coffea canephora and the amount of area (in hectares) suitable or not for mechanization.



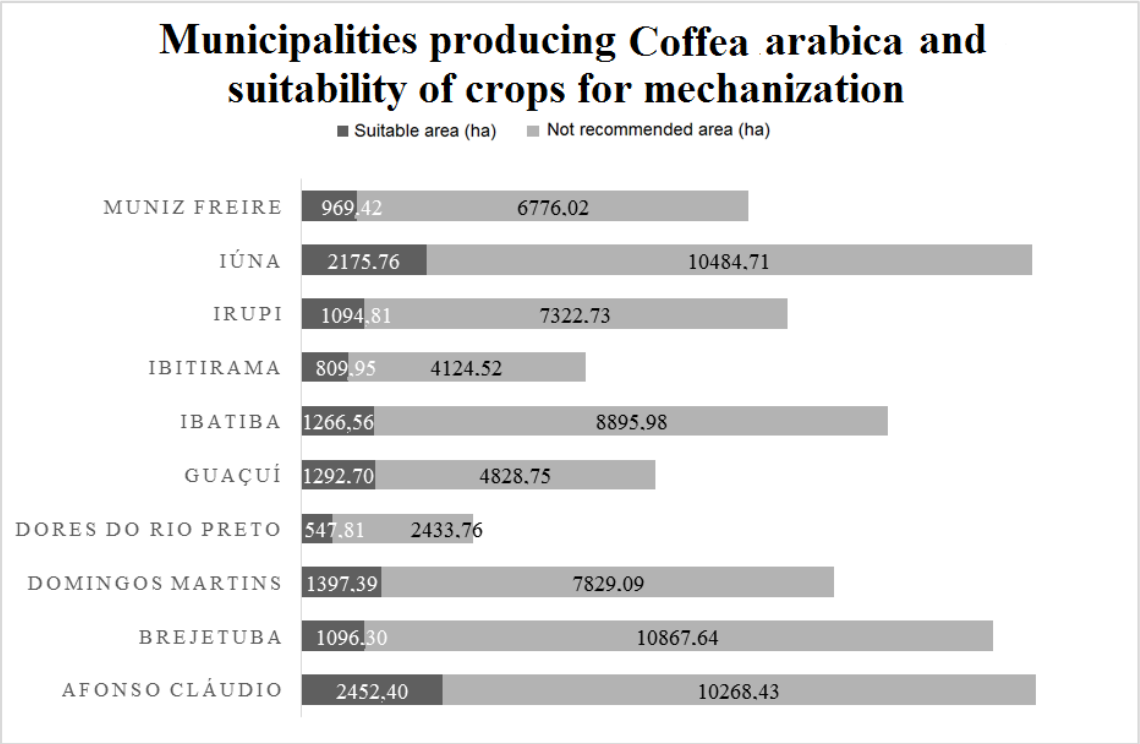
For the municipalities of Iúna, Ibatiba, Brejetuba, Guaçuí, Irupi, Domingos Martins, Ibitirama, Afonso Cláudio, Muniz Freire and Dores do Rio Preto, located in the southern and south-central parts of the state (Figure 8), the conditions for mechanization are opposite to those observed in the municipalities of the northern portion, i.e., areas with coffee plantations that are not recommended for mechanization predominate (Figure 9). Among these municipalities, Guaçuí, Afonso Claudio, and Dores do Rio Preto are the ones with the highest percentage of mechanized area, being 21.12%, 19.28%, and 18.37%, respectively (Figure 9).

Figure 8 – Visualization of the municipalities in the southern portion of Espírito Santo that stand out in coffee growing and the classification of the cultivated areas of these municipalities according to their suitability for mechanization.



Souza et al. (2019), confirm this information when they state in their work that for the State of Espírito Santo, with 37% of the total area in Arabica coffee and 63% in conilon coffee, the potential for mechanization is extremely high, very high and high, to 3.8%; 8.1% and 12.6% for Arabica and 33.3%; 18.9% and 14.7% for conilon, respectively, and that about 32.6% and 14.1% of the area with Arabica coffee and conilon are not recommended for use in mechanized operations because they have a slope between 20 and 30%. Thus, the greater restriction to the mechanization of Arabica coffee plantations elucidates the possibility of intensifying the use of agricultural machinery in conilon coffee plantations due to the larger suitable area.

Figure 9 - Graph of the ten municipalities with the highest production of Coffea arabica and the amount of area in hectares, suitable or not for mechanization.



4 CONCLUSION

The State of Espírito Santo has 428,482.6 hectares of crops planted with Coffea canephora and Coffea arabica. They are a total of 21.6%; 11.3% and 11.2% that have extremely apt, very apt and apt mechanization potential; 10.7% moderately suitable and 45.3% of the area not recommended for mechanized activities.

In general, 188,750.46 hectares of coffee areas are suitable for mechanization and 239,732.13 hectares are not recommended for mechanization. Therefore, the state has the largest number of areas in production with a slope greater than 15%.

The municipalities with high production of Coffea canephora have the crops with the greatest aptitude for mechanization when compared to the municipalities with high production of Coffea arabica.

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