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Thermal zoning for mountain coffee crops in the Matas de Minas region, Brazil

Gabriela Regina Ferreira[1], Williams Pinto Marques Ferreira[2], Thuane Katiúcia Moreira Barbosa[3], Alixandre Sanquetta Laporti Luppi[4], Marcos Antônio Vanderlei Silva[5]

[1]Geographer, Master student in Applied Meteorology, Department of Agricultural Engineering, Federal University of Viçosa, 36570-900, Viçosa MG, Brazil. gabriela.regina@ufv.br (corresponding author). [2]Meteorologist, Doctor in Agricultural Engineering, Researcher at the Brazilian Agricultural Research Corporation-UFV Campus, 46 Vila Gianneti, 36570-000, Viçosa MG, Brazil. [3]Agricultural and Environmental Engineer, Master student in Agricultural Systems Engineering, University of São Paulo, ESALQ, Biosystems Department, 13418-900, Piracicaba SP, Brazil. [4]Agronomist Engineer, Doctoral student in Agricultural Engineering, Federal University of Viçosa, Department of Agricultural Engineering, 36570-900, Viçosa MG, Brazil. [5]Agronomist Engineer, Doctor in Agricultural Meteorology, Adjunct professor at State University of Bahia, Campus IX, 47802-682, Barreiras BA, Brazil.

R E S U M O

A relação da altitude com a temperatura do ar causa mudanças sensíveis no microclima, na adaptação de espécies vegetais e, consequentemente, no sucesso na introdução de espécies para cultivo agrícola. Com objetivo de comprovar a influência dessas variáveis na distribuição das lavouras cafeeiras foi realizado em Minas Gerais o zoneamento com base na altitude e exigências térmicas do café arábica para a região das Matas de Minas. Foi feito o zoneamento térmico com base altitude e exigências térmicas do café arábica e coletados pontos amostrais de lavouras cafeeiras in situ. Pode-se observar, a partir dos resultados, que aproximadamente 95% lavouras das Matas de Minas situam-se em áreas termicamente favoráveis à cultura do café arábica, sendo possível inferir que a distribuição das lavouras está condicionada à altitude e ao valor médio anual da temperatura do ar. Concluiu-se que a altitude e temperatura tem condicionado a distribuição das lavouras na região, destacando-se o fator altitude.
Palavras chave: Mapeamento, altitude, aptidão térmica, produção de café

A B S T R A C T

The effect of altitude and temperature generates different microclimates, affecting the adaptation of plants, and the implementation of agricultural crops. Thus, the objective of this work was to evaluate the effect of these variables on the distribution of coffee plantations in the Matas de Minas region, through the development of a thermal zoning based on the local altitudes, and thermal requirements of Arabica coffee, and coffee samplings in this region. Approximately 95% of the crops in the Matas de Minas region is in thermally favorable areas for the cultivation of Arabica coffee, thus, the distribution of crops is dependent on the altitude and average annual air temperature. Therefore, altitude and temperature have conditioned the distribution of coffee crops in the region, especially altitude.
Key-words: Mapping, altitude, thermal suitability, coffee production

Introduction

In the agricultural sector, Coffee is one of the most exported products of Brazil. The state of Minas Gerais is divided into four large producing regions and stands out with 68.2% of the Arabic coffee area in the country; and its mesoregions Zona da Mata and Rio Doce are responsible for 30% of the national production (CONAB, 2017). The Matas de Minas region is in these mesoregions, known for its production of excellent-quality coffee (Ferreira et al., 2016).

According to Ferreira et al. (2016), the Matas de Minas region is mainly located in the mesoregion Zona da Mata. The Zona da Mata and

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South of Minas mesoregions present similar characteristics of relief, and technologies used in coffee crops; the Mountain Coffee is found in these regions, representing around 70% of the coffee production of Minas Gerais state, and is produced in more than 220 municipalities (Vilela and Rufino, 2010).

According to Pinheiro (2015), special and artisanal coffees are produced in the Matas de Minas region, with predominance of the *Coffea Arabica* species, and the varieties Catuaí vermelho and Catuaí amarelo (Silveira, 2015). According to Matiello et al. (2010), *Coffea Arabica* is classified as a topical plant of altitude, which is native to Ethiopia and was adapted to humid climates with mild temperatures.

Sant'anna Neto (2005) states that altitude and relief have a distinct and marked effect on the different regional climates of the Southeast region of Brazil. This effect is seen in the Matas de Minas region due to its rough topography.

The relief of a region can affect its climate due to variation in ground surface altitude, and the shape and direction of its slopes (Fritzsons et al., 2008). This affects the behavior of humans, and animal and plant production.

Climatic zoning, and environmental variables contribute to the planning and management of agricultural systems, thus determining the areas that are suitable for the implementation and development of a given crop (Avelino et al., 2005; Barbosa et al., 2012; Silva et al., 2015; Ferreira et al., 2016; Meireles et al., 2016).

Altitude and daylight time are some of the environmental factors that most affect coffee crops (Zaidan et al., 2017). According to Sediyama et al. (2001), air temperature is one of the most marked characteristics among climate elements that characterize the mountain microclimate, and it is very important to the coffee crop cycle and, consequently, to the quality of the final product.

Considering the relevance of coffee production in the Matas de Minas region, studies on the correlation between altitude and air temperature and the coffee plantations contribute to the agricultural planning of a region.

The main objective of this work was to develop the thermal and topographic maps of the Matas de Minas region and evaluate the effect of these variables on the distribution of coffee plantations in the region.

Methodology

The Matas de Minas region is in the Mata Atlantic Forest biome, in eastern Minas Gerais state, between the coordinates 40º50'S to 43º36'S and 18º35' to 21º26'W. This region is composed of 63 municipalities that belong to the Vale do Rio Doce and Zona da Mata mesoregions (Figure 1). This region has a predominantly mountainous and rough relief, which results in various microclimates.

The thermal characterization of the region was based on exploratory analysis of topographic data. A 54-year (1961 to 2014) series of daily average air temperature data were used to map the thermal zoning. These data are from a network of 61 conventional meteorological stations of the Brazilian National Institute of Meteorology in the state of Minas Gerais and neighboring states (Rio de Janeiro, São Paulo, Bahia, Espírito Santo and Goiás). These data were organized in spreadsheets using the Excel 2007 software (Microsoft), and converted into a point-type vector file of the shapefile format (*.shp) for spatialization of the air temperature in the ArcMap 10.1 software, following the methodology proposed by Santos et al. (2015).

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Figure 1. Location of the Matas de Minas region in the state of Minas Gerais, Brazil. Source: www.cafepoint.com.br/radares-tecnicos/gerenciamento/matas-de-minas-uma-regiao-produtora-de-cafe-em-movimento-94511n.aspx.

The meteorological data in vector format was used for the air temperature spatialization with multiple linear regression; the average maximum and minimum air temperatures were used as dependent variables, and latitude, longitude, and altitude as independent variables.

According to Antonini et al. (2009), statistical analysis of multiple linear regression can expand the database and estimate the air temperature in a region. The equations generated by the multiple linear regression were used to estimate the temperatures as a function of longitude, latitude, and altitude (Antonini et al., 2009). This methodology has been used in several studies in different states of Brazil, (Medeiros et al., 2005; Cargnelutti Filho et al., 2008; Antonini et al., 2009; Lyra et al., 2011; Eugenio et al., 2014), due to its practicality and acceptable accuracy degree, and because average air temperature is dependent on the latitude, and mainly on the altitude of the region.

Thus, the multiple linear regression coefficients were calculated and the air temperature matrix image for the state of Minas Gerais was obtained using map algebra, according to Equation 1:

$$Y = \beta_0 + \beta_1 \text{longitude} + \beta_2 \text{latitude} + \beta_3 \text{altitude}$$
Eq.1

wherein Y is the air temperature (°C); latitude, and longitude are given in degrees (°); altitude is according to the Digital Elevation Model (m); and β ($_0$, $_1$, $_2$, $_3$) are the coefficients of the regression equation.

The elevation matrix image, known as Digital Elevation Model (MDE), was obtained from the National Institute for Space Research (INPE); it had a resolution of 30 meters and was elaborated in the TOPODATA project of the Shuttle Radar Topography Mission (Valeriano, 2008).

Assuming that the model always underestimates or overestimates the results, the real averages of the 61 meteorological stations and the estimates by the model were subjected to the t-Student hypothesis test with a significance level of 5%.

Thermal and topographical information of the municipalities that compose the Matas de Minas region was obtained and redesigned using the Universal Transverse Mercator Projection Zone 23S, and Datum SIRGAS 2000 (IBGE,

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2005). Maps of the minimum and maximum air temperature were developed based on the averages of the 54-year data series, and the average annual temperature map was developed using the Raster Calculator tool.

Suitability classes were then determined based on the thermal requirements of the coffee plant, using the average air temperature ranges according to Ngolo (2014) (Table 1). The different suitability (temperature ranges) were subjected to a spatial reclassification to identify areas with different suitable temperatures for the cultivation of Arabica coffee in the Matas de Minas region.

Table 1. Suitability classes of average annual temperature (°C) for coffee crops.

Authors	Suitable	Marginal	Unsuitable	Location
Alègre (1959), Camargo (1977), Coste (1989) e Carr (2001)	18 - 22	22 – 23	> 23	Brazil
Instituto Brasileiro do Café (1986)	18 - 22	22 – 23	< 18 and > 23	Brazil
Matiello (1991)	18 – 22.5	22.5 – 24	< 18 and > 24	Brazil
Sediyama et al. (1999)	18 – 23.5		< 18 and > 24	State of Minas Gerais

Elaborated by Gabriela Regina Ferreira. Adapted from Ngolo (2014).

The temperature ranges used to make the thermal suitability map were reclassified based on the minimum, average and maximum temperature described in Table 1. Areas presenting temperatures lower than 18°C or higher than 24°C were considered unsuitable for the crop, since they present too cold or too warm weathers; areas presenting temperatures between 18°C and 22.5°C were considered suitable; and areas with temperatures varying between 22.5°C and 24°C were considered marginals.

The geographical coordinates of 435 coffee plantations were recorded in 30 municipalities, among the 63 that constitute the Matas de Minas region. The selection of municipalities was according to Silveira (2015), i.e., considering their economic contribution to the regional coffee production; geographic, and practical limitations; location in continuous areas; and limiting financial aspects for the field work.

The suitable, unsuitable, and marginal areas for coffee crops were identified and the percentage of crops located in the suitable, unsuitable, and marginal areas was found, according to the reclassified values of each point in the map, considering the 435 coffee plantations analyzed.

Results and Discussion

The correlation between altitude and air temperature of the region was analyzed using the average, and minimum air temperature maps (Figure 2a, 2b) developed for the Matas de Minas region with the 54-year data series.

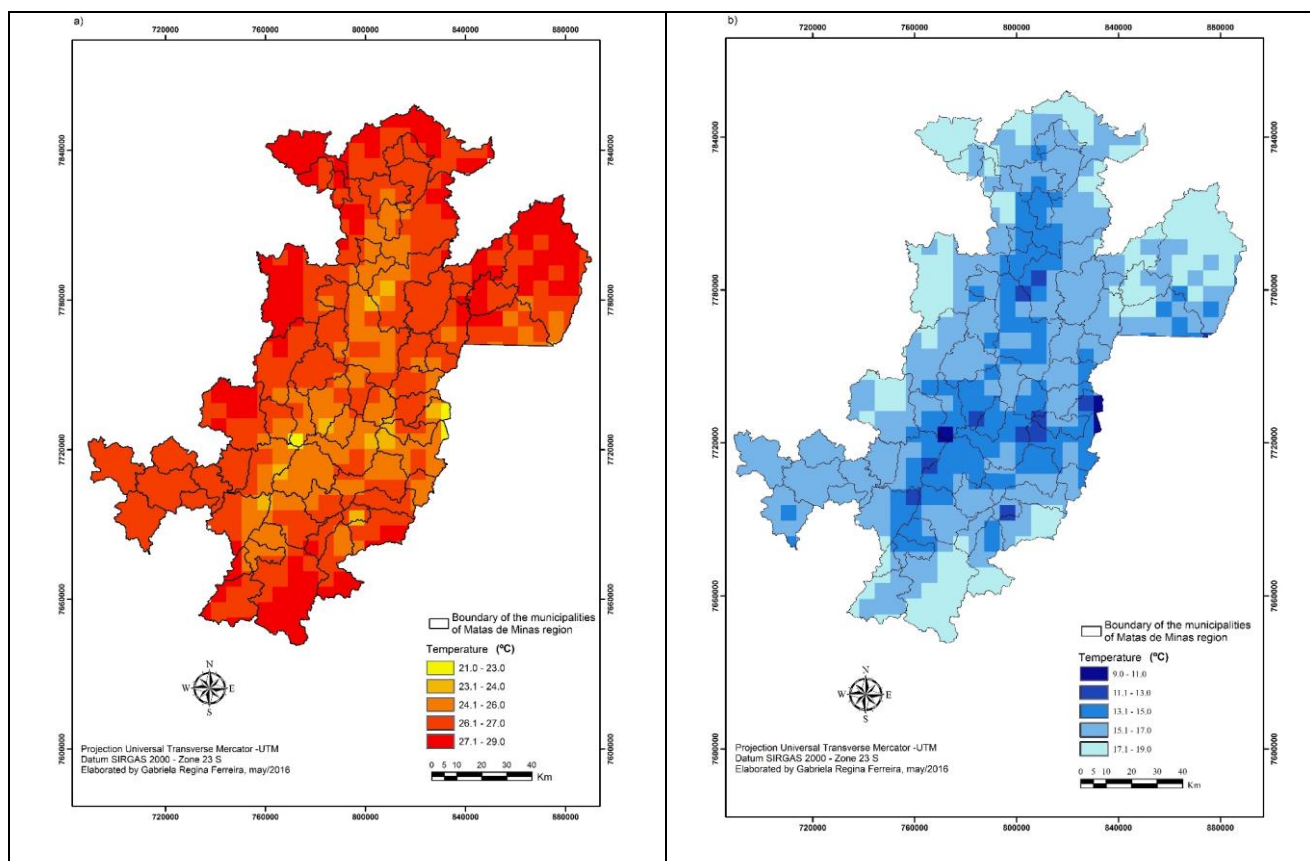*Ferreira, G. R., Ferreira, W. P. M., Barbosa, T. K. M., Luppi, A. S. L., Silva, M. A. V.*

Figure 2. Maps of the average maximum air temperature (a) and average minimum air temperature (b) in the Matas de Minas region based on a 54-year data series (1960 to 2014).

The altitude of the Matas de Minas region varies between 174 and 2,829 m (Figure 3). The extreme north, northeast, northwest, and south of the region are the areas with lower altitude, varying between 124 and 599 m. An extension in the south stands out with the lowest altitudes. The average altitudes vary from 600 to 1,000 m in the central area of the region, and altitudes above 1,000 m are found in the Brigadeiro mountain range, in the western part of the Pico da Bandeira, and in the mountain range between the municipalities of Manhuaçú and Simonesia.

The areas with higher altitudes (Figure 3) coincide with those with lower minimum (Figure 2B) and maximum (Figure 2A) air temperatures. The lowest averages of minimum and maximum temperatures are found in the Alto Caparaó, Serra do Brigadeiro, and Serra de São José, in Luisburgo; and in the highest parts of the border between the municipalities of Manhuaçu and

Simónésia, whose altitudes are close to 1,000 m. The highest averages of minimum and maximum temperatures are found in areas with lower altitudes, such as the eastern Muriaé, and north of the Matas de Minas region, in the municipalities of Mutum, Caratinga, and Raul Soares, which are areas with altitude of approximately 600 m.

Thus, the spatialization of the air temperature showed the effect of the physiography (altitude) on the spatial pattern of air temperature distribution in the Matas de Minas region, with high temperatures in low-altitude areas and low temperatures in high-altitude areas.

According to the Student's t-test, maximum temperature data of 47 areas showed significant variation, however, the maximum difference was 2.9°C; and the minimum temperature data of 49 areas presented significant variation, with maximum difference of 2.4 °C.

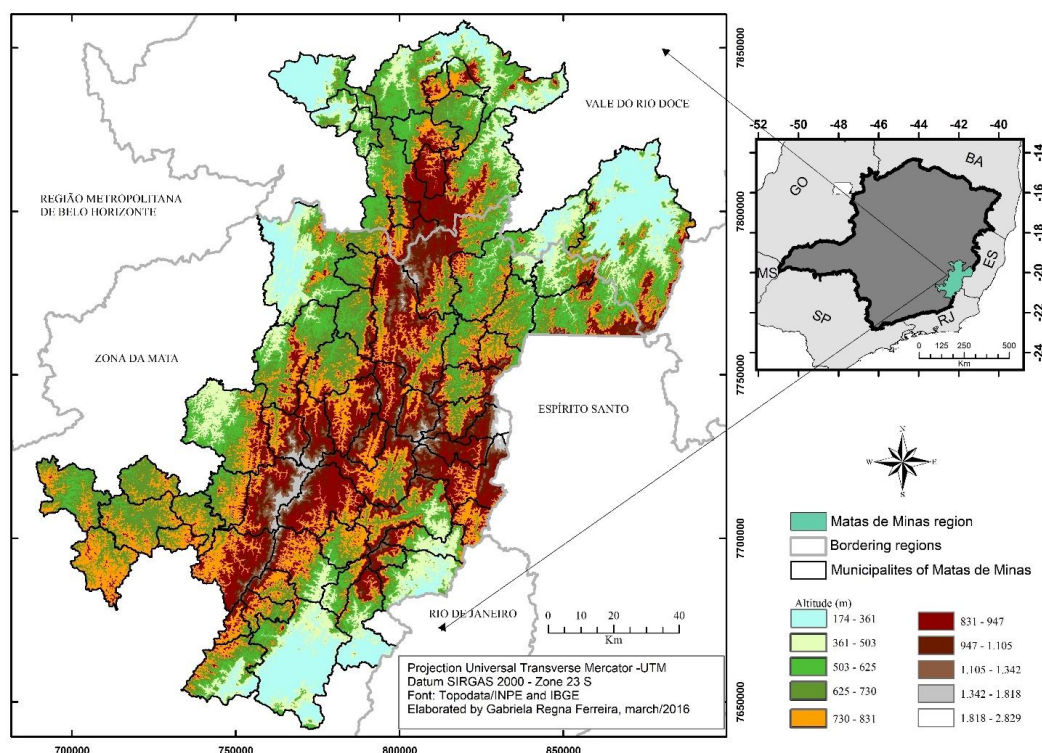*Ferreira, G. R., Ferreira, W. P. M., Barbosa, T. K. M., Luppi , A. S. L., Silva, M. A. V.*

Figure 3. Altimetric map and location of the Matas de Minas region in the state of Minas Gerais, Brazil.

The average annual temperature of the Matas de Minas region varied between 15ºC and 24ºC (Figure 4), with a mean of 22ºC and standard deviation of 1.5ºC. Thus, it is within the suitable range for the cultivation of Arabica coffee. In general, the average annual temperature of large part of the Matas de Minas region ranges from 18.1°C to 22.5 °C, with areas above 1,300 m, presenting the lowest average temperatures (15.4°C to 18°C).

Regarding the crop location, Bernardes et al. (2012), evaluated the distribution of coffee plants in different altitudes, slopes, soil classes and directions of slopes, and found that altitude is the major limiting factor for the implantation of coffee crops.

According to the altimetric map, regions that are near to the higher areas presented fewer crops (Figure 5), due to the high slopes of the mountains. These high slopes make the handling and harvesting difficult, even when performed manually. Moreover, the low temperatures in these regions also hinder the implementation of

coffee crops, prolonging the coffee cycle and decreasing the production.

The central area of the region is characterized by lower slopes when compared to the Serra do Brigadeiro, Pico da Bandeira, and the mountain range between the municipalities of Manhuaçú and Simonésia, presenting a higher concentration of crops. Moreover, this region has a mild weather and low slopes that facilitate harvesting and transport of the production.

Considering the adopted range of thermal suitability for coffee crops (Table 1), the areas in the Matas de Minas region with higher altitudes are unsuitable due to their low temperatures; and those with lower altitudes, mainly to the north and south of the Matas de Minas region are marginal or unsuitable because of their high temperatures (Figure 6).

Regarding the thermal suitability and distribution of the coffee crops, approximately 95% of the 435 mapped crops are in suitable areas, approximately 1.4% in unsuitable areas, and 3.6% in marginal areas.
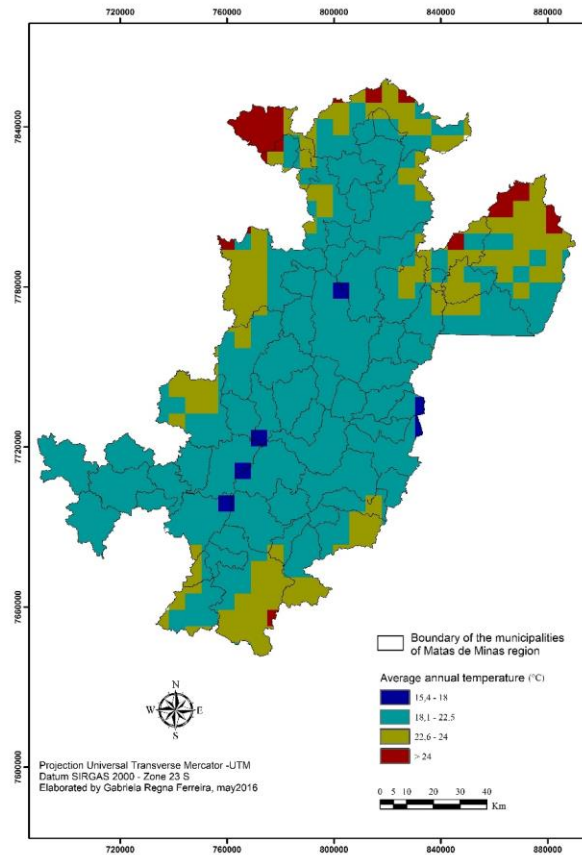
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Figure 4. Average annual temperature of Matas de Minas region in the state of Minas Gerais, Brazil.
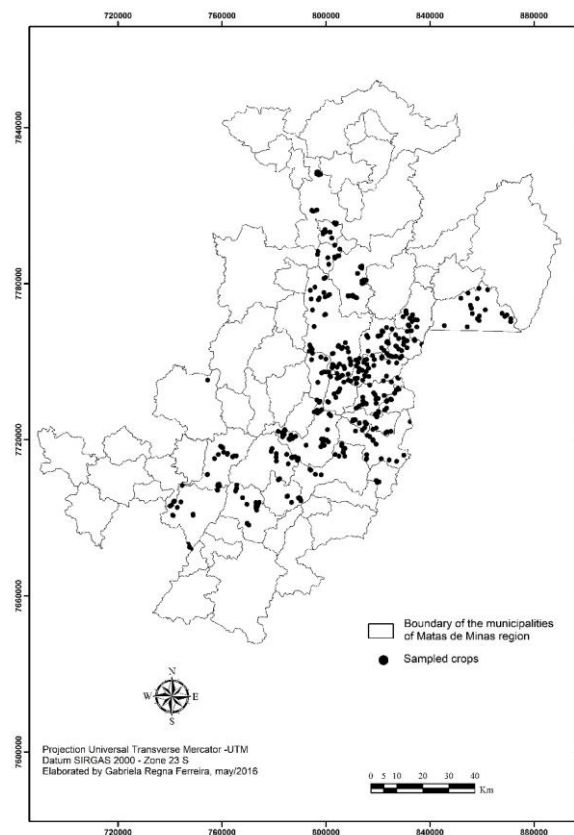

Figure 5. Location and concentration of sampled crops in the Matas de Minas region in the state of Minas Gerais, Brazil.

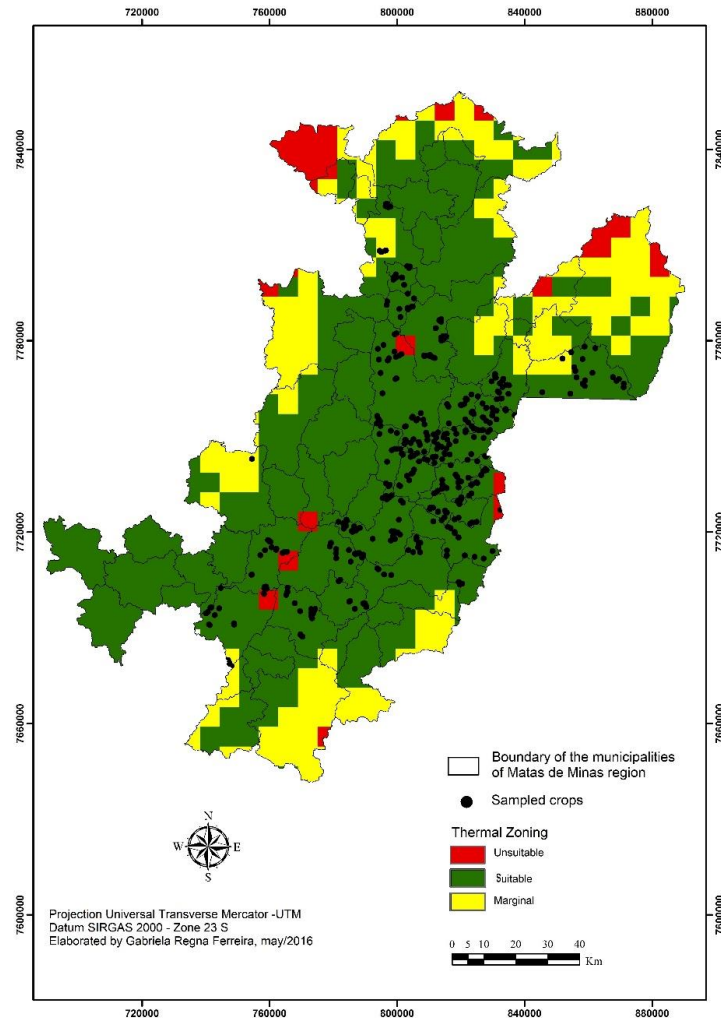*Ferreira, G. R., Ferreira, W. P. M., Barbosa, T. K. M., Luppi , A. S. L., Silva, M. A. V.*

Figure 6. Thermal suitability for Arabica coffee crops (variety Catuaí) in Matas de Minas region in the state of Minas Gerais, Brazil.

The suitable areas for coffee crops, considering only the average air temperature, were in the municipalities Caratinga, Simonésia, and Ubaporanga in the north; Manhuaçú, Manhumirim, Alto Caparaó and Divino in the central areas and further east; and part of Araponga, Fervedouro, Matipó, Porto Firme, Cajuri and Paula Cândido in the southern and western areas.

Araponga and Espera Feliz are large coffee producing regions, where some small areas were unsuitable for coffee crops due to low temperatures, mainly because these areas present the highest altitudes of the region. This may be due to the delimited range adopted for analysis, in which regions that present annual average temperatures below 18ºC are unsuitable for coffee crops.

Unsuitable areas in Araponga had average minimum temperatures of 11ºC and annual average temperatures of approximately 17.6ºC. Unsuitable areas in Espera Feliz had minimum average temperatures of 9ºC with annual averages temperatures of 15.6ºC. No crops were found in areas affected by high temperatures—above 24ºC.

Approximately 95% of the crops were in thermal suitable areas for coffee crops, 1.4% in unsuitable areas, and 3.6% in marginal areas. Areas with very low temperatures, which are unfavorable to coffee crops, were found in the highest altitudes of the region, while areas with high temperatures were found in the lower altitudes, in north and south of the Matas de Minas region.

The thermal zoning, and the information on the environmental variables that can affect the

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coffee production can generate greater yields and better-quality products. In an analysis of the beverage quality, determined by sampling 312 points in 14 municipalities in the Matas de Minas region, the altitude and position of the crop production site were the main variables affecting the coffee quality (Silva et al., 2015, Ferreira et al., 2016).

Considering the effect of the altitude combined with temperature is fundamental for the implementation of a coffee plantation; their action can affect even the final quality of the beverage.

Conclusions

Most of the Matas de Minas region has areas with suitable average air temperature for coffee crops.

Altitude is a determinant factor for the distribution of coffee plantations.

The physiographic and thermal characteristics found for the region can assist in the planning of new crops in the Matas de Minas region.

Further evaluation of the data trending, and researches with classification through satellite images to identify a largest number of crops in the region are suggested.

Acknowledgments

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