AGROCLIMATIC ZONING OF ARABICA COFFEE CROPS IN THE REGION OF LAVRAS, MINAS GERAIS, BRAZIL

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Abstract: Coffee growing is the most relevant agricultural activity in the state of Minas Gerais. Arabica coffee (*Coffea arabica* L.) is the most widely cultivated in the state and is more sensitive to the climate, requiring milder temperatures for commercial production. Water deficit and air temperature are the main factors used in the agroclimatic zoning of coffee, requiring annual water deficits below 150 mm and an average annual air temperature between 19°C and 21°C for suitability for cultivation. The Lavras region has municipalities with contrasting areas planted with Arabica coffee, being located in a transition zone of the growing crop. Therefore, the objective was to use interpolated climatic surfaces of mean monthly temperature and monthly precipitation, with high spatial resolution (30 seconds) of the WorldClim2 project, in order to perform the agroclimatic zoning for Arabica coffee in 11 municipalities around Lavras, Minas Gerais, Brazil. The water balance was calculated by the Thornthwaite method and the contour of existing plantations was obtained from a survey conducted by EPAMIG for the year 2018. The annual water deficit varied from 19 mm to 47 mm and the temperature from 17.5°C to 20.5°C. According to the geospatial analysis and scientific geovisualization techniques, it was observed that most of the region is suitable for cultivation of Arabica coffee, but spatial variations in water deficit may interfere with productivity and economic viability of implementation in certain areas.

Keywords: Arabica coffee, Climate zones, Water balance, Worldclim2.

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INTRODUCTION

Currently coffee is one of the main products to be industrialized in the world. Being cultivated in approximately 80 countries (BICHO et al., 2013). Among these productions, the Arabica (*Coffea arabica* L.), Canephora (*Coffea canephora*) and Liberian (*C. liberica* Bull.) species can be found (DAVIS et al., 2006). In this context, Brazil is presented as the largest coffee producer in the world, with a climate suitable for the cultivation of coffee species, especially Arabica and Canephora coffee (MARTINS et al., 2022).

Arabica coffee (*Coffea arabica* L.), the main agricultural product of Minas Gerais in gross production value, accounts for about 70 percent of the coffee sold in the world, producing superior quality drinks, sweet flavors and higher prices (ILLY; VIANI, 1996; LEROY et al., 2006; ROMANI et al., 2012; BALANÇO…, 2021; SOUZA et al., 2004). Compared to the coffee of the canephora species (*Coffea canephora* L.), popularly known by the Conilon variety, Arabica coffee has different thermal requirements, greater sensitivity, requiring lower temperatures (CHEMURA et al., 2021). For the commercial production of Arabica coffee, the average annual temperature considered favorable is between 19°C and 21°C, while the annual water deficit should be less than 150 mm

(MATIELLO, 1991; THOMAZIELLO et al., 2000). In addition to the mentioned parameters, it is necessary to evaluate the monthly distribution of soil water availability. According to the phenology of the coffee crop, water needs vary according to the phenological phase, being high during the reproductive period and low during the harvest and rest phase, between June and September (MATIELLO, 1991; BONOMO, 1999; CAMARGO; CAMARGO, 2001; PETEK; SERA; BATISTA F., 2009; CARVALHO et al., 2013). Water availability after the dry period is the main component that induces flowering, so water deficit occurring before the onset of rains contributes to the formation of a more uniform flowering (MEIRELES, 2009).

Interpolated climate surfaces of high spatial resolution present potential to evaluate climatic attributes at regional scale (NEW et al., 2002). The region around Lavras, Minas Gerais, is located in a transition zone of the coffee activity in the state, presenting municipalities with large areas planted with Arabica coffee in contrast with bordering municipalities with few areas dedicated to coffee cultivation. High-resolution climate surfaces raise the possibility of investigating variations in climate on a municipal scale and determining, in greater detail, local characteristics for cultivation of Arabica coffee. Agroclimatic zoning on a regional scale is an important aid for analyzing the agricultural potential of a crop in a given location, indicating areas where cultivation is climatically appropriate, bringing undeniable benefits for local agricultural planning (WOLLMANN; GALVANI, 2013). The application and evaluation of new interpolation techniques in agricultural zoning, as well as the increase in computing capacity and the emergence of new packages in a free software environment, offer prospects for improved detail, ease of application and reduced costs in terms of obtaining data, climate characterization and dissemination of information.

To test whether the new interpolation techniques are capable of improving the detail of climate zoning, the objective of this study was to use geospatial analysis and scientific geovisualization techniques in order to evaluate the performance of high spatial resolution climate surfaces (30 seconds) of the WorldClim2 (FICK; HIJMANS, 2017) project for average monthly air temperature and monthly precipitation to perform the agroclimatic zoning of Arabica coffee at the municipal level and identify the potential for rainfed coffee cultivation in 11 municipalities around Lavras, Minas Gerais, Brazil.

MATERIAL AND METHODS

Study area

Based on the digital municipal mesh products (IBGE, 2021a) and municipal agricultural production (IBGE, 2021b), 11 municipalities covering Lavras and its surroundings were selected (Figure 1). The study area is located in a bordering position between the South of Minas, Midwest and Center-South regions. According to Figure 1, obtained using the ggplot2 (WICKHAM et al., 2021) and tmap (TENNEKES, 2018) package in R, the set of municipalities covers a transition zone in the cultivation of Arabica coffee. In the western portion there is a large presence of coffee crops, while in the eastern direction their presence becomes less frequent. The municipalities of Nepomuceno and Carmo da Cachoeira had the largest areas destined to Arabica coffee harvesting in 2020, around 11,000 hectares each. The elevation map of the state was prepared from the Shuttle Radar Topography Mission (SRTM) digital elevation model obtained from the getData function in the R (HIJMANS et al., 2020) raster package.

Climate surfaces of temperature and precipitation

Climate surfaces of monthly precipitation and average air temperature were used. The data correspond to the historical period 1970-2000, downscaled to 30 seconds of spatial resolution (approximately 1 km in the area of interest) and made available by the WorldClim2 (FICK; HIJMANS, 2017) project.

The climate surfaces were clipped in the area of interest using the subset obtained from the union of the polygons of the municipalities of Lavras, Nepomuceno, Carmo da Cachoeira,

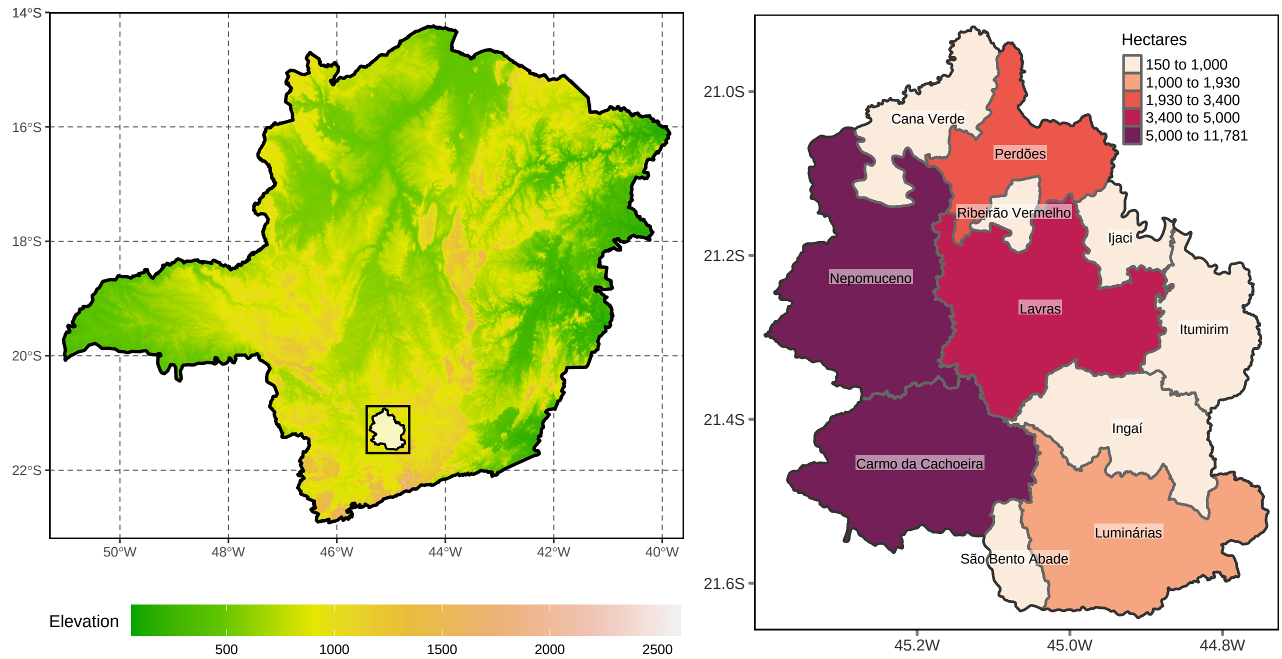

Figure 1: Elevation map (m) (left) and area destined for Arabica coffee harvest in 2020 (right).

Ribeirão Vermelho, Cana Verde, Perdões, Ijací, Itumirim, Ingaí, Luminárias and São Bento Abade, using the raster (HIJMANS et al., 2020) and sf (PEBESMA, 2018) packages in R.

Water deficit and air temperature

The input parameters for calculating the water deficit u sing t he T hornthwaite method are the mean monthly air temperature and the accumulated monthly rainfall. First, the potential evapotranspiration (ETp) is determined. The balance of water in and out of the soil is calculated for each month, taking into account the storage capacity adopted. The monthly deficits are added together to obtain the annual water deficit.

Based on the clipped climate surfaces, the monthly water balance was calculated by the method of Thornthwaite and Mather (1955) using the bioclim package (SERRANO-NOTIVOLI; LONGARES; CÁMARA, 2022) in R, considering available water capacity (AWC) of 100 mm. Monthly and annual water deficit r epresentations were obtained using the stars (PEBESMA, 2022) package in R.

The annual mean air temperature was calculated and its visual representation was obtained with the package stars (PEBESMA, 2022). A scale of 0.25°C was adopted in the legend to cover the temperature ranges of interest.

The contours of coffee crops in the region were obtained from a survey conducted by EPAMIG in 2018 (EMATER, 2018). The annual water deficit surface was disaggregated in 9 times by bilinear interpolation and clipped by the contour of the crops and acquired the histogram of the clipping, in order to verify the frequency of distribution of the crops in relation to water deficit.

Agroclimatic zoning

The areas were classified as suitable, restricted, or unsuitable according to thermal and hydric parameters proposed by (MATIELLO, 1991) (Table 1). The areas corresponding to the three conditions were calculated in hectares.

Table 1: Water and temperature requirements for the Arabica coffee tree.

Condition	Water deficit annual (mm)	Annual mean temp. (°C)
Suitable	< 150	$19 - 22$
Restricted	$150 - 200$	$18 - 19$ and $22 - 23$
Unsuitable	> 200	< 18 e > 23

The suitable regions present favorable conditions for the cultivation of Arabica coffee, supplying the thermal and hydric requirements. It should be noted that the suitable condition of a region does not mean the complete supply of the climatic needs of the plant for maximum productivity, but the climatic feasibility of implementing the crop in the region. The restricted regions are those that do not meet the requirements within a tolerable limit, and may become suitable if it is possible to implement practices to mitigate the limiting factors. The unsuitable areas, on the other hand, are not economically viable for implementation and exploration of the crop due to inadequate climatic conditions.

RESULTS AND DISCUSSION

Water deficit

According to the monthly distribution of the water deficit (Figure 2), the period of the year when the greatest deficits of water occur in the soil was identified as the months of June to August. The maximum monthly deficit was 22 mm, occurring in August and recovered almost completely at the end of September. According to (SILVA; REBOITA, 2013), the wettest period in Minas Gerais is from October to March. The dry season begins in April, but with the 100mm CAD adopted, the first signs of water deficit were only observed in May.

According to the phenological development of Arabica coffee for tropical conditions in Brazil proposed by Camargo and Camargo (2001), the reproductive phase of the plant begins in September, with water availability being the main factor that induces flowering. Therefore, water deficiency before the opening of flowers, from July to August, as long as it is not excessive, favors the induction of a more uniform bloom in the coffee tree (MEIRELES, 2009). The monthly distribution of water deficit in the region (Figure 2) was favorable for the cultivation of Arabica coffee. Regarding the annual water deficit (Figure 3), the municipalities of São Bento Abade, Luminárias, Ingaí and Itumirim showed the largest deficits, while in the municipality of Nepomuceno the deficits were the smallest.

Despite the variation of the water deficit in the region, all the values were within the range considered suitable for Arabica cultivation. Even if a certain area fits the climatic suitability for cultivation, it is known that water deficit affects productivity, especially in the reproductive phase of the crop (DAMATTA; RAMALHO, 2006). Several studies and proposals of agrometeorological models have water deficit as one of the main components for predicting productivity (TOSELLO; ARRUDA, 1962; PICINI et al., 1999; CAMARGO; SANTOS et al., 2003).

The clipping of the water deficit by the contour of the coffee crops (Figure 4) showed the lowest presence of crops in the eastern portion of the study area. The density plot (Figure 5) shows that the great majority of plantations were located in regions with an annual water deficit between 35 and 25 mm. The higher concentration of planted area in Nepomuceno and Carmo da Cachoeira may be related, among other factors, to the higher economic return in productivity due to the lower water deficit. The coffee growing in the south of the state is marked by the presence of small properties (BROGGIO; DROULERS; GRANDJEAN, 1999) and rugged terrain (VILAS BOAS, 2020), making mechanization difficult. These factors contribute to the increase in production costs, causing producers to prefer regions where there is a higher return in productivity.

Air temperature

Few areas presented average annual temperatures below 19°C (Figure 6). Practically the entire region is suitable in terms of thermal requirements for coffee growing. The lowest mean annual temperature was observed in the municipality of Luminárias, in a mountainous region where the rocky outcrops themselves are a limiting factor. In general, the lowest temperatures are found in higher-altitude regions where the terrain is often more rugged, causing a topographical limitation for crop mechanization (TAVARES et al., 2018). The highest temperatures were observed around the Rio Grande, where the altitude is lower.

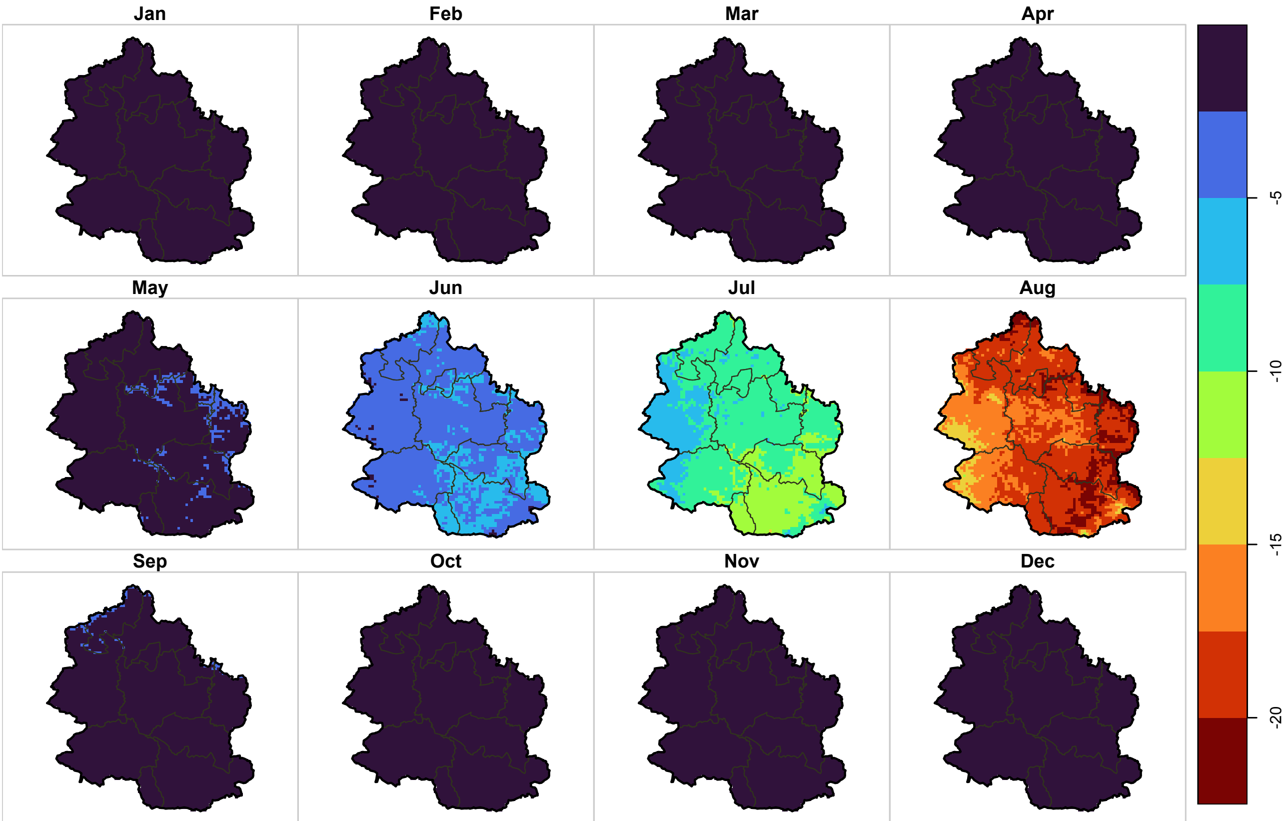

Figure 2: Monthly water deficit (mm) in the region around Lavras, Minas Gerais, Brazil.

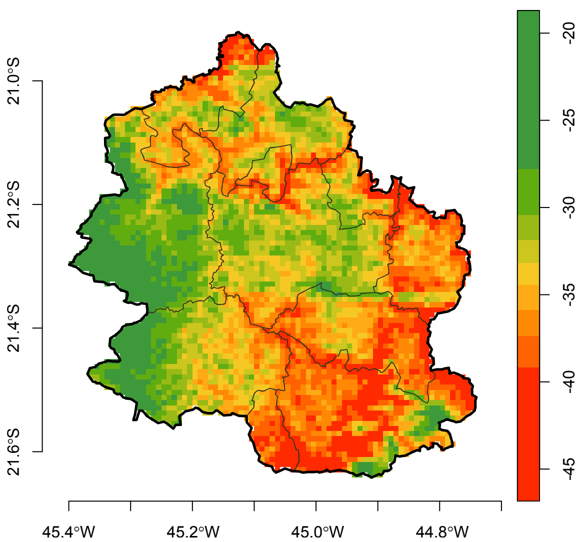

Figure 3: Annual water deficit (mm) in the region around Lavras, Minas Gerais, Brazil.

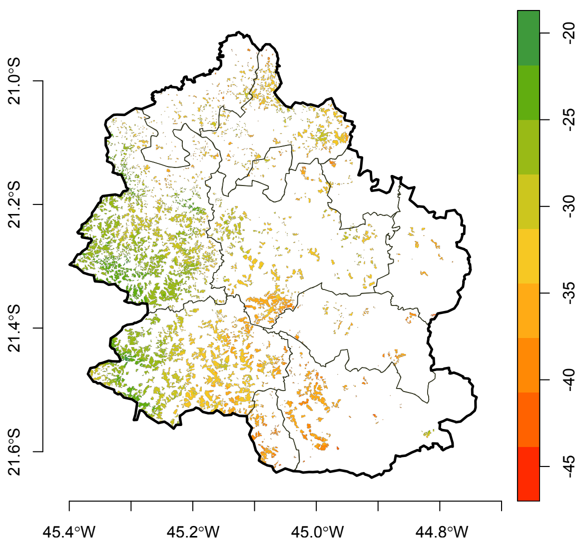

Figure 4: Annual crop water deficit (mm) in coffee crops around Lavras, Minas Gerais, Brazil.

Although almost the entire region is suitable in terms of thermal requirements, it is known that growing coffee in colder zones, a factor highly related to altitude, contributes to a slower maturation of the fruit, adding greater quality and the possibility of producing specialty coffees (ALVES et al., 2011).

Agroclimatic zoning

Practically the entire region was climatically suitable for growing Arabica coffee (Figure 7). Few regions were restricted and only one was unsuitable, in both cases due to low temperatures. The values in terms of area are

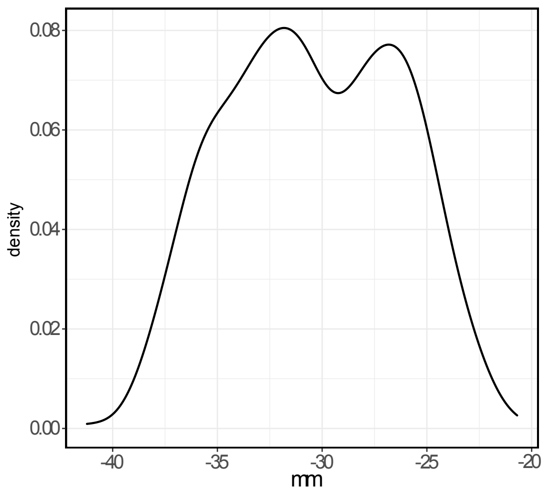

Figure 5: Distribution of water deficit density in coffee plantations around Lavras, Minas Gerais, Brazil.

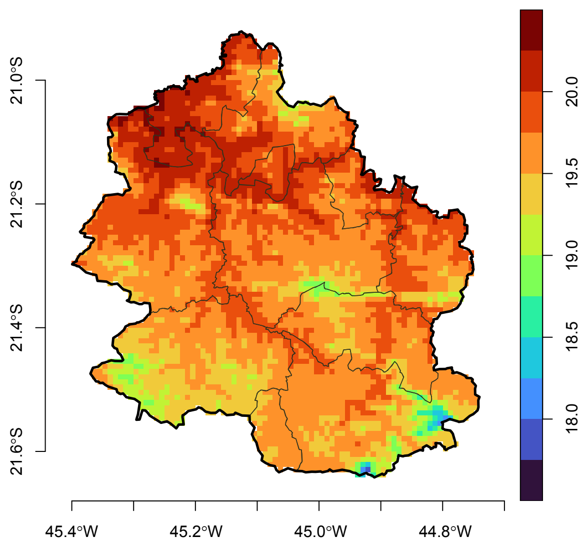

Figure 6: Mean annual temperature (°C) in the region around Lavras, Minas Gerais, Brazil.

shown in Table 2. The observed restricted and unsuitable areas were located in regions of higher altitude and low temperatures, showing the capacity of the temperature climate surface to capture variations with high spatial resolution.

The results showed the climatic suitability of the region, identified in previous zoning studies (EVANGELISTA; CARVALHO; SEDIYAMA, 2002; SEDIYAMA et al., 2001). Nevertheless, the high spatial resolution and the technique of interpolation of the data used, which takes into account the relief spatial variation, allowed a level of detailing that is not verified in the cited studies. Also according to the zoning presented

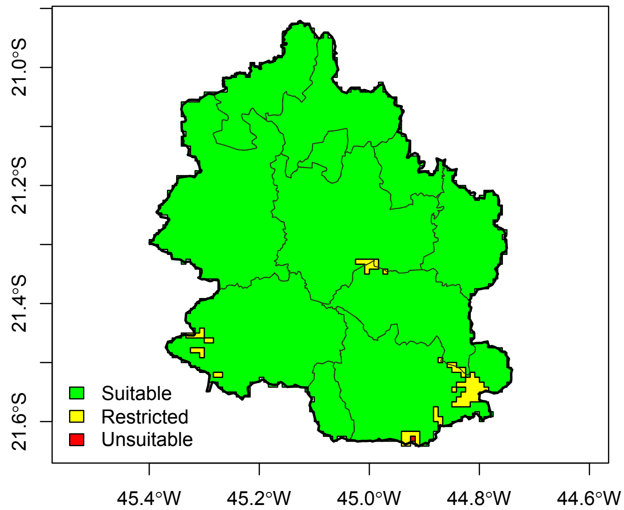

Figure 7: Agroclimatic zoning of Arabica coffee in the region around Lavras, Minas Gerais, Brazil.

by (SEDIYAMA et al., 2001), the study area is outside a probability higher than 30% of frost occurrence.

Despite the climatic suitability, the identified variations in water deficit can generate varied effects on productivity. An analysis of economic feasibility must be performed according to water deficit, mean annual temperature, considering the social context of the region and other factors that interfere with productivity in order to implement the crop in the location. In regions with lower temperatures one can take into consideration the possibility of producing specialty coffees that present a good potential for financial return (MARCOMINI; MIRANDA, 2009), especially in the context of small properties and rugged terrain.

Table 2: Area of the agroclimatic zones obtained for growing Arabica coffee in the region around Lavras, Minas Gerais, Brazil.

Condition	Area (ha)
Suitable	336766
Unsuitable	5911
Restricted	80
Total	342757

CONCLUSIONS

The high spatial resolution climate surfaces used showed good potential in capturing municipal scale climate nuances. The months of greatest water deficit were identified as June, July and August. The return of water availability occurred in September, with almost the entire region with no water deficit in early October.

The maximum and minimum annual water deficit was 47 mm and 19 mm, respectively. The average annual temperature ranged between 17.5 and 20.5°C. Most of the coffee crops in the region in 2018 were located in areas with a water deficit of 25 to 35 mm. The results obtained with the use of climate surfaces showed a higher concentration of coffee crops in areas with lower annual water deficit.

It was possible to determine the agroclimatic zoning for Arabica coffee in the study region and few areas presented restricted or unsuitable conditions. We observed that 336,766 hectares were classified as suitable, 5,911 hectares as restricted and only 80 hectares as unsuitable. In general, the region presented favorable climatic characteristics for the commercial production of Arabica coffee. However, the economic viability, represented by the productivity obtained with the rainfed system, must be considered to determine the climatic viability of coffee growing in the region.

REFERENCES

ALVES, H. M. R. et al. Características ambientais e qualidade da bebida dos cafés do estado de Minas Gerais. **Informe Agropecuário**, Belo Horizonte, v. 32, n. 261, p. 1–12, 2011.

BALANÇO do Agronegócio de Minas Gerais 2021. [S. l.: s. n.], 2021. P. 58.

BICHO, N. C. et al. Quality assessment of Arabica and Robusta green and roasted coffees - A review. **Emirates Journal of Food and Agriculture**, v. 25, p. 945–950, 2013. DOI: 10.9755/ejfa.v25i12.17290.

BONOMO, R. **Análise da irrigação na cafeicultura em áreas de cerrado**. 1999. F. 224. PhD Thesis – Universidade Federal de Viçosa, Viçosa.

BROGGIO, C.; DROULERS, M.; GRANDJEAN, P. A Dinâmica Territorial da Cafeicultura Brasileira – Dois Sistemas de Produção em Minas Gerais. **Revista Território**, Rio de Janeiro, v. 04, n. 06, p. 73–91, 1999.

CAMARGO, Â. P.; CAMARGO, M. B. P. Definition and outline for the phenological phases of arabic coffee under Brazilian tropical conditions. **Bragantia**, v. 60, p. 65–68, 2001. DOI: 10.1590/S0006-87052001000100008. In: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0006-87052001000100008&lng=pt&tlng=pt>.

CAMARGO, M. B. P.; SANTOS, M. A. et al. Modelo agrometeorológico de monitoramento e de estimativa de quebra de produtividade como subsidio à previsão de safra de café (Coffea arabica L.) In: p. 75–76.

CARVALHO, I. R. et al. Water demand of crop agronomic interest. **Enciclopédia Biosfera**, v. 9, p. 969–985, 2013.

CHEMURA, A. et al. Climate change and specialty coffee potential in Ethiopia. **Scientific Reports**, v. 11, p. 8097, 2021. DOI: 10.1038/s41598-021-87647-4. In: <https://doi.org/10.1038/s41598-021-87647-4>.

DAMATTA, F. M.; RAMALHO, J. D. C. Impacts of drought and temperature stress on coffee. **Brazilian Journal of Plant Physiology**, v. 18, n. 1, p. 55–81, 2006.

DAVIS, A. P. et al. An annotated taxonomic conspectus of the genus Coffea (Rubiaceae). **Botanical Journal of the Linnean Society**, v. 152, n. 4, p. 465–512, 2006. DOI: 10.1111/j.1095-8339.2006.00584.x..

EMATER. **Projeto Observatório da Agricultura de Minas Gerais**. Portal do Café de Minas. 2018. In: <https://www.emater.mg.gov.br/portal.do?flagweb=novosite_geoportal_sobre>.

EVANGELISTA, A. W. P.; CARVALHO, L. G. de; SEDIYAMA, G. C. Zoneamento climático associado ao potencial produtivo da cultura do café no Estado de Minas Gerais. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 6, n. 3, p. 445–452, 2002. DOI: 10.1590/S1415-43662002000300011.

FICK, S. E.; HIJMANS, R. J. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. **International Journal of Climatology**, v. 37, p. 4302–4315, out. 2017. DOI: 10.1002/joc.5086. In: <https://onlinelibrary.wiley.com/doi/10.1002/joc.5086>.

HIJMANS, R. J. et al. **raster: Geographic Data Analysis and Modeling**. 2020. In: <https://rspatial.org/raster>.

IBGE. **Malha municipal 2021. Mapas, bases e referenciais, bases cartográficas, malhas digitais**. 2021. In: <https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html?=&t=acesso-ao-produto>.

________. **PAM - Produção Agrícola Municipal**. 2021. In: <https://sidra.ibge.gov.br/pesquisa/pam/tabelas>.

ILLY, A.; VIANI, R. **Espresso coffee: the chemistry of quality**. 2nd. San Diego: Academic Press, 1996. P. 253.

LEROY, T. et al. Genetics of coffee quality. **Brazilian Journal of Plant Physiology**, v. 18, n. 1, p. 229–242, 2006. DOI: 10.1590/S1677-04202006000100016.

MARCOMINI, G. R.; MIRANDA, J. M. de. Aspectos econômico-financeiros da produção de café convencional e café especial. In: VI SIMPÓSIO DE PESQUISA DOS CAFÉS DO BRASIL, p. 1–6.

MARTINS, D. S. et al. Coffea arabica and C. canephora as host plants for fruit flies (Tephritidae) and implications for commercial fruit crop pest management. **Crop Protection**, v. 156, 2022. DOI: 10.1016/j.cropro.2022.105946.

MATIELLO, J. B. **O café: do cultivo ao consumo**. São Paulo: Globo, 1991. P. 320.

MEIRELES, E. J. L. **Fenologia do Cafeeiro: condições agrometeorológicas e balanço hídrico do ano agrícola 2004–2005**. Brasília, DF: Embrapa Informação Tecnológica, 2009.

NEW, M. et al. A high-resolution data set of surface climate over global land areas. **Climate Research**, v. 21, p. 1–25, 2002.

PEBESMA, E. Simple Features for R: Standardized Support for Spatial Vector Data. **The R Journal**, v. 10, n. 1, p. 439–446, 2018. DOI: 10.32614/RJ-2018-009. In: <https://doi.org/10.32614/RJ-2018-009>.

________. **stars: Spatiotemporal Arrays, Raster and Vector Data Cubes**. 2022. In: <https://r-spatial.github.io/stars/>.

PETEK, M. R.; SERA, T.; BATISTA F., Inês C. de. Exigências climáticas para o desenvolvimento e maturação dos frutos de cultivares de coffea arabica. **Bragantia**, Campinas, v. 68, n. 1, p. 169–181, 2009.

PICINI, A. G. et al. Desenvolvimento e teste de modelos agrometeorológicos para a estimativa de produtividade do cafeeiro. **Bragantia**, Campinas, v. 58, n. 1, p. 157–170, 1999.

ROMANI, S. et al. Evaluation of coffee roasting degree by using electronic nose and artificial neural network for off-line quality control. Versão inglesa. **Journal of food science**, United States, v. 77, n. 9, p. c960–5, set. 2012.

SEDIYAMA, G. C. et al. Zoneamento agroclimático do cafeeiro (Coffea arabica L.) para o estado de Minas Gerais. **Revista Brasileira de Agrometeorologia**, v. 9, n. 3, p. 501–509, 2001.

SERRANO-NOTIVOLI, R.; LONGARES, L. A.; CÁMARA, R. bioclim: An R package for bioclimatic classifications via adaptive water balance. **Ecological Informatics**, v. 71, 2022. DOI: https://doi.org/10.1016/j.ecoinf.2022.101810.

SILVA, E. D.; REBOITA, M. S. Precipitation study for Minas Gerais state, Brazil. **Revista Brasileira de Climatologia**, v. 13, p. 120–136, 2013. DOI: 10.5380/abclima.v13i0.33345.

SOUZA, F. F. et al. **Características das principais variedades de café cultivadas em Rondônia**. 1ª. Porto Velho: Embrapa Rondônia, 2004. P. 21.

TAVARES, P. S. et al. Climate change impact on the potential yield of Arabica coffee in southeast Brazil. **Reg Environ Change**, p. 873–883, 2018. DOI: 10.1007/s10113-017-1236-z.

TENNEKES, M. tmap: Thematic Maps in R. **Journal of Statistical Software**, v. 84, n. 6, p. 1–39, 2018. DOI: 10.18637/jss.v084.i06.

THOMAZIELLO, R. A. et al. **Café arábica: cultura e técnicas de produção**. Campinas: Instituto Agronômico, 2000. P. 82.

TOSELLO, R. N.; ARRUDA, H. V. de. Correlation between oficial estimates of coffee yields and rainfall distribution in the state of São Paulo. **Bragantia**, v. 21, p. 449–465, 1962. DOI: 10.1590/S0006-87051962000100027. In: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0006-87051962000100027&lng=pt&tlng=pt>.

VILAS BOAS, L. G. A cafeicultura na região de planejamento Sul de Minas e no município de Nepomuceno, Minas Gerais. **Geosaberes**, Fortaleza, v. 11, p. 656–673, 2020. DOI: 10.26895/geosaberes.v11i0.972.

WICKHAM, H. et al. **ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics**. 2021. In: <https://cran.r-project.org/web/packages/ggplot2/index.html>.

WOLLMANN, Cássio Arthur; GALVANI, Emerson. Zoneamento agroclimático: linhas de pesquisa e caracterização teórica-conceitua. **Sociedade & Natureza**, v. 25, n. 1, p. 179–189, 2013. DOI: 10.1590/S1982-45132013000100014.