CONILON Coffee

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The Coffea canephora produced in Brazil

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Agroclimatic Zoning for Conilon Coffee Culture in the State of Espírito Santo

Renato Corrêa Taques and Gilmar Gusmão Dadalto

1 INTRODUCTION

The conilon coffee is the major agricultural product of Espírito Santo, present in 64 of the 78 municipalities in the State and it is responsible for the generation of the greater part of the income and jobs in rural areas in most of them. Currently, Espírito Santo has an occupied area of approximately 310 thousand hectares and a production of 9.95 million bags per year (CONAB, 2014), reason that gives the State the title of the largest national producer of conilon.

The State of Espírito Santo is characterized by a natural diversified framework, with different climatic environments, which has allowed the cultivation of varieties of conilon coffee in regions of low altitudes and higher temperatures, and the varieties of arabica coffee in the highest areas and mild temperature.

The national and international competitiveness that the Capixaba coffee is subject requires a permanent quest for greater economic efficiency, social justice and environmental balance, factors that require training of farmers, access to information, reducing production costs, improving productivity and quality of the product and placing the crops in more appropriate areas. In this way, the observance of the suitability or natural vocation of rural spaces for the establishment of coffee has fundamental importance to the achievement of sustainable and competitive development.

Regardless the cultural treatments carried out in coffee plantation, environmental factors related to climate and soil, when in adverse conditions, complicate and may even make the commercial exploitation of coffee impractable, conditioning low productivity. Thus, the agroclimatic zoning for the coffee cultivation is a tool to support the planning and consolidation of the coffee activity, allowing the knowledge of the most suitable areas for cultivation and enabling to maximize the economic efficiency in balance with the environment, basic conditions for its sustainability over time.

In this chapter, it is presented the agroclimatic zoning for conilon coffee plantation in the state of Espírito Santo by identifying the categories of aptness, based on consistent historical series of climatic data and more precise (fine spatial resolution) predictive models, obtained from the distribution of probability multivariate statistics and geostatistics.

2 AGRICULTURAL ZONING

At the beginning of the 1960s, the so called Associação de Crédito e Assistência Rural do Espírito Santo - Acares (Association of Rural Credit and Assistance of Espírito Santo), an institution that originated the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural - Incaper (Capixaba Institute for Research, Technical Assistance and Rural Extension), elaborated the first agricultural zoning for the state of Espírito Santo. Since then, several studies related to the agricultural zoning were developed, either on the initiative of public institutions, or as publications of independent authors.

In these studies, we observe that the climatic characteristics of the regions, associated to the information research and experimentation, were decisive for the definition of different categories of aptness. These surveys usually provide qualitative nature subsidies with limited level of detail, rarely enabling the quantification of the mapped areas due to the reduced cartographic maps scale used in zoning.

It was also observed that the climate is the primary factor of agroecological aptness in natural feasibility studies for deployment and development of agricultural activities. The limitations and possibilities stemming from the soil and other natural factors, although equally important, depend on the climatic possibilities and limitations; (SILVA; ASSAD, 1998). In addition, the characteristics of the soil, especially those that affect the productivity of coffee, such as fertility, are more likely to be modified than the climatic conditions.

Matiello (1998) presents the map of the suitable areas for the cultivation of conilon coffee in Brazil. In Figure 1, it is possible to have a macro idea of the areas where there are thermal and water conditions for the conilon coffee. It is possible to observe a significant suitable area for cultivation in Espírito Santo, placing the State in a prominent position in the national panorama.

More recent studies (SEDIYAMA et al., 2001; ANDRADE et al., 2012) proposed the climatic aptness zoning of coffee cultivation using thematic maps generated in geographic information systems (SIG), Pezzopane et al. (2010) indicated that the climate risk zoning, which incorporates probabilistic aspects, quantifying the chances of a particular adverse phenomenon occur at critical stages of culture. Overall, these studies use a mathematical modeling of annual temperature average and the interpolation of the sequencial hydric balance results of the observation points (meteorological stations and rain gauges).

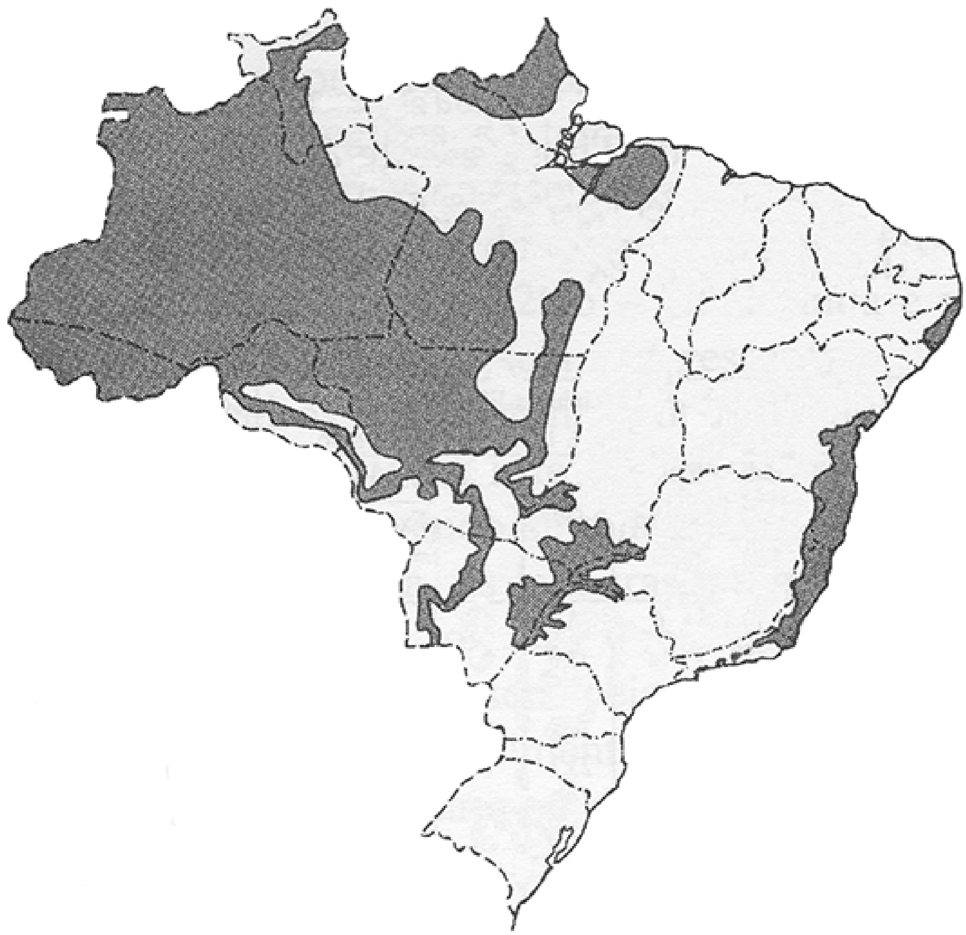

Figure 1. Map of suitable areas for the cultivation of conilon coffee in Brazil.

Source*:* Matiello (1998).

3 MODELING FOR THE AGROCLIMATIC ZONING

3.1 SPATIAL DATA BASE

For the study, it was built a spatial database to store the input data and the results of the processing. It was established a regular grid of points, with spacing of 500 x 500 meters (0.04 points per hectare) covering the whole territory of Espírito Santo. This grid of points was used as the basis for the prediction and modeling of agroclimatic zoning.

The DEM digital elevation model (MDE - Modelo Digital de Elevação) was obtained from the images of the *Shuttle Radar Topographic Mission* (SRTM), with a spatial resolution of 90 meters (CGIAR, 2015). The DEM was hydrologically consisted to eliminate small imperfections with the use of ArcGIS Desktop 10 program tools (ESRI, 2015). Continuous surfaces were also generated, in raster format, for the latitude and longitude values, in degrees, and distance from the coast, in meters.

The DEM values of elevation, latitude, longitude and distance from the coast of each point of regular grid were used as covariates in predicting the values of average temperature and the calculation of the potential evapotranspiration.

The observation points (meteorological stations and rain gauges) were georeferenced and added to the spatial database, in datum SIRGAS 2000 and Universal Transverse Mercator (UTM zone 24 south) projection system.

It was also used in the information plan with the limit of municipalities, which are part of the Sistema Integrado de Bases Geoespaciais do Estado do Espírito Santo, 2015 - GEOBASES (Integrated System of Geospatial Bases of Espirito Santo State). The regional division of the State was determined based on Law 9.768, dated 12/28/2011 of the Government of the State of Espírito Santo.

3.2 SPATIAL PREDICTION OF AVERAGE TEMPERATURE

The spatialisation of the monthly and annual average temperature values was performed based on the data series of meteorological stations of the Integrated Network of Surface Meteorological Observations (Inpe, Inmet, Incaper). 15 meteorological stations in operation were selected in the period that comprises January 2000 and December 2013 (14 years).

The value of the average monthly temperature of each meteorological station was obtained from the arithmetic mean of the month values in the study period. The absent values of monthly temperature, represented by NR (not rated) in historical series were disregarded in the mean calculation. The average annual temperature of each station was calculated from the arithmetic mean of the average monthly temperature.

The spatial prediction of average temperatures was performed using the method of Regressão Linear Múltipla - RLM (Multiple Linear Regression - MLR). For this, four covariate predictors were used: elevation, latitude, longitude and distance from the coast The Stepwise method was used to select the covariates of MLR models. The regression models, which are represented by mathematical equations that describe the relationship between the average temperature and the covariates were evaluated by the coefficients R^2 values.

The processing of data for spatial prediction of average temperatures was performed in the statistical software R (R DEVELOPMENT CORE TEAM, 2015), using stats package functions (*The R Stats Package*).

3.3 SPACIAL PREDICTION OF RAINFALL

For the precipitation spatialization, 106 observation points (95 rain gauges and 11 meteorological stations) were selected with a minimum of 30 years of data in the historical series, from January 1974 to December 2013. The series of precipitation data was obtained on the rainfall database of the Sistema Nacional de Informações sobre Recursos Hídricos - SNIRH (National System of Information about Water Resources), the Agencia Nacional das Águas - ANA (Water National Agency) (ANA, 2015) and on the meteorological stations database of the Integrated Network of Surface Meteorological Observations (Inpe, Inmet, Incaper).

The annual precipitation was calculated by summing the monthly precipitation from January to December of each year, and the precipitation in the summer period, adding the monthly precipitation in September of the previous year to February of each year. The sum that presented one or more missing values of monthly precipitation, within the annual or estival period, were represented as NA and not considered in the calculations.

The precipitation estimate for the two periods (Annual and summer) was determined using a probabilistic model of Gamma distribution, with probability level of 0.75. The parameter form (α) and scale (β) were determined by the method of maximum likelihood (CATALUNHA et al., 2002).

The spatial prediction of annual precipitation and summer period estimates was performed using the geostatistical method of Ordinary Kriging. The adjustment of the semivariogram models was performed by the method of Ordinary Least Squares. The Kriging results were evaluated by the determination coefficient (R^2) of *leave-one-out* cross-validation.

The geostatistical analyzes were performed on the statistical software R (R DEVELOPMENT CORE TEAM, 2015), using functions of the gstat package (*Spatial and Spatio-Temporal Geostatistical modeling, Prediction and Simulation*) and MASS (*Support Functions and Datasets for Venables and Ripley's MASS*).

3.4 EVAPOTRANSPIRATION AND *HYDRIC DEFICIT*

Potential monthly evapotranspiration (ETp) was estimated by the Thornthwaite method (THORNTHWAITE, 1948), which by definition represents the monthly total evapotranspiration that would occur in the thermal conditions (average temperatures), in a standard month of 30 days, when each day would have 12 hours of photoperiod.

The ETp was corrected to obtain the ETP (monthly potential evapotranspiration) accordong to the number of days and the month average photoperiod. The value of the month average photoperiod was equaled to the duration of the direct solar radiation of the 15th day of each month. The solar radiation model of the ArcGIS Desktop 10 (ESRI, 2015) program was used to estimate the duration of daily solar radiation from the DEM.

Similar to the precipitation, the annual potential evapotranspiration (ETPa) was calculated adding the ETPs of January to December, and the potential summery evapotranspiration (ETPe), adding the summer period ETPs (September to February). The annual water *deficit* (DA) and the water deficit in the summer period (ED) were obtained by subtracting the evapotranspiration precipitation of the respective periods (annual and summer).

3.5 APTNESS CATEGORIES

For robusta coffee (*Coffea canephora*), the regions with annual average temperatures between 22 °C and 26 °C are considered apt. The regions with annual average temperatures lower than 22 °C are considered marginal or inapt (MATIELLO, 1991).

Regarding climatic water factors, Matiello (1991) considers: apt the regions with annual water *deficit* (DA) less than 200 mm; apt with water restriction the regions with DA between 200 mm and 400 mm; and with water impediment the regions with DA higher than 400 mm. In the last two cases, the conilon cropspresent very favorable responses to the practice of irrigation and afforestation for sparse shading.

Dadalto and Barbosa (1997) also relate parameters for the water deficit in the summer period (DE), which corresponds to the months of September to February, period of greater water demand of conilon. In this case, the regions with DE bellow 40 mm are considered apt; apt with water restriction the regions with DE between 40 mm and 100 mm, and with water impediment the regions with DE higher than 100 mm.

The increase of the productive potential of conilon, registered in recent decades, which boosted the productivity from 60 to 120 processed bags per hectare, and the search for the improvement of the grains and drink quality require more favorable water conditions to achieve better results. The delimitation of water aptness categories was reviwed to better represent the current demands of the culture (Table 1).

Table 1. Aptness categories for conilon coffee regarding the *annual and summer water deficit*

Apteness Categories	Annual Water *Deficit* DA (mm)	Summer Water *Deficit* DE (mm)
Apt	0	0
Light water restriction	0 a 200	0 a 40
Moderate water restriction	200 a 400	40 a 80
Severe water restriction	> 400	> 80

Source: Adpted from Dadalto and Barbosa (1997).

The definition of aptness categories considered the possibility of using the existing technologies and recommended by Incaper for conilon, such as better cultivars, fertilization, pruning, among others, to improve productivity. The use of irrigation is recommended for the aptness categories with water restrictions, enabling the conilon coffee cultivation in these areas.

The agroclimatic aptness categories for conilon coffee in Espírito Santo were stratified as it follows:

• **Apt areas** - are those where climatic conditions are more favorable to the conilon coffee cultivation, with high production potential and low climatic risk;

• **Apt areas with light water restriction** - are those where climatic conditions allow the conilon coffee cultivation. However, the use of supplementary irrigation is recommended in certain periods of drought;

• **Apt areas with moderate restriction** - are those where climatic conditions allow the cultivation of conilon coffee, although marginally, which means that there are possibilities to commercially produce the conilon coffee with a lower potential of production and higher climatic risks compared with the apt areas. In this case, it is necessary a more frequent use of supplementary irrigation;

• **Apt areas with severe water restriction** - are those that present strong water limitations that make the commercial cultivation of conilon coffee unfeasible or present high risks to the activity success. In these areas, the use of supplementary irrigation is essential;

• **Areas with thermal impediment** - are the highest one, presenting mild temperatures (annual average temperatures lower than 22 °C), where it is not recommended the conilon coffee cultivation.

The determination of the aptness category was performed by map algebra (cross-linking data) obtained for the annual average temperature, annual water *deficit* and water *deficit* in the summer period (Figure 2). The area of each category was obtained by multiplying the number of pixel cells of each category by the area of the cell, which is 25 hectares (500 m x 500 m).

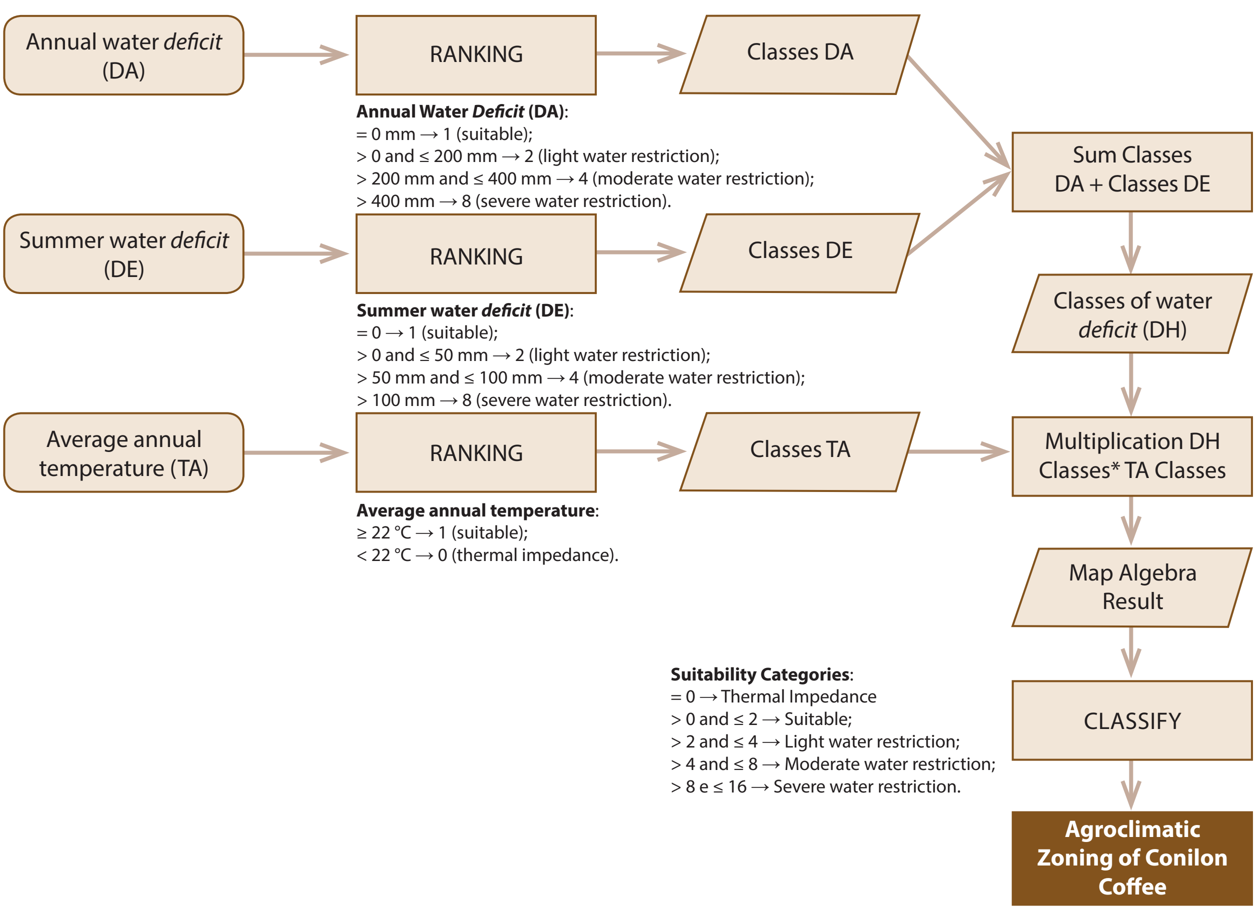

Figure 2. Flowchart of the stages to obtain the agroclimatic zoning map for conilon coffee in the State of Espirito Santo.

4 RESULTS

In the annual average temperature maps, obtained from the MLR models (Table 2), temperatures lower than 22 °C are observed, mainly in the mountainous and southern regions (Figure 3). The mathematical model shows that the limit of altitude for annual average temperatures lower than 22 °C varies between 400 m and 580 m approximately, depending on the geographical position of the site (latitude and longitude).

Table 2. Regression equations adjusted for the model of the normal average temperatures (monthly and yearly) and respective coefficients of determination (R^2) for the State of Espírito Santo

Period	a0	a1	a2	a3	a4	R^2
January	26,090000	-0,006161			0,000018	0,96
February	8,380000	-0,006695		-0,449100	0,000016	0,95
March	-13,676599	-0,006375	0,743295	-1,359134		0,95
April	-10,123391	-0,006648	0,724468	-1,232359		0,95
May	-0,019848	-0,006696	0,880160	-1,005476		0,95
June	-6,605661	-0,007289	0,893785	-1,150427		0,94
July	-14,905478	-0,007515	0,775452	-1,286587		0,94
August	-36,696622	-0,007711	0,800460	-1,851139		0,94
September	-36,043954	-0,006895	0,797441	-1,849529		0,97
October	-43,815441	-0,006829	0,822870	-2,091689		0,96
November	24,264256	-0,006166			0,000021	0,96
December	25,540000	-0,005960			0,000018	0,97
Annual	-21,825125	-0,006758	0,746480	-1,509947		0,96

Regression equation parameters: a0 = intercept; a1 =elevation (m); a2 = latitude (degrees); a3 = longitude (degrees); a4 = distance from the coast (m).

Dadalto and Barbosa (1997) also observed the variation in the altitude limit for the conilon coffee cultivation, from field observations and culture knowledge. In this study, it was reported that the conilon coffee has a high potential for cultivation up to 500 m altitude, to the south of the right bank of the Doce River basin divider and up to 600 m, to the north of this divider.

The experimental semivariograms of Ordinary Kriging process for spatial prediction of annual and cumulative precipitation in the summer period, were adjusted to the exponential model (Figure 4). The annual and summer period accumulated precipitation follow approximately the same distribution, with higher volumes of precipitation in the central mountain region and in Caparaó. The lower volumes of precipitation are observed in the extreme north and part of the north-central regions of the State (Figure 5).

The highest values of annual (ETPa) and summer (ETPe), potential evapotranspiration are observed predominantly in the extreme north of the state and, also occurring in the north-central region, in the Doce River valley and in the southern region of the state, in the valleys of Rivers Itapemirim and Itabapoana (Figure 6), regions highlighted in red. The extreme nothern region also features the lowest volumes of precipitation, which combined with the high value of evapotranspiration, results the highest water deficiencies (Figure 7).

Considering the limits of water *deficit* for the conilon coffee aptness, the summer water *deficit* (DE) was the one that presented a greater impact, if compared with the annual water *deficit* (DA), and is main responsible for the delimitation of areas with severe water restriction for conilon coffee in the State.

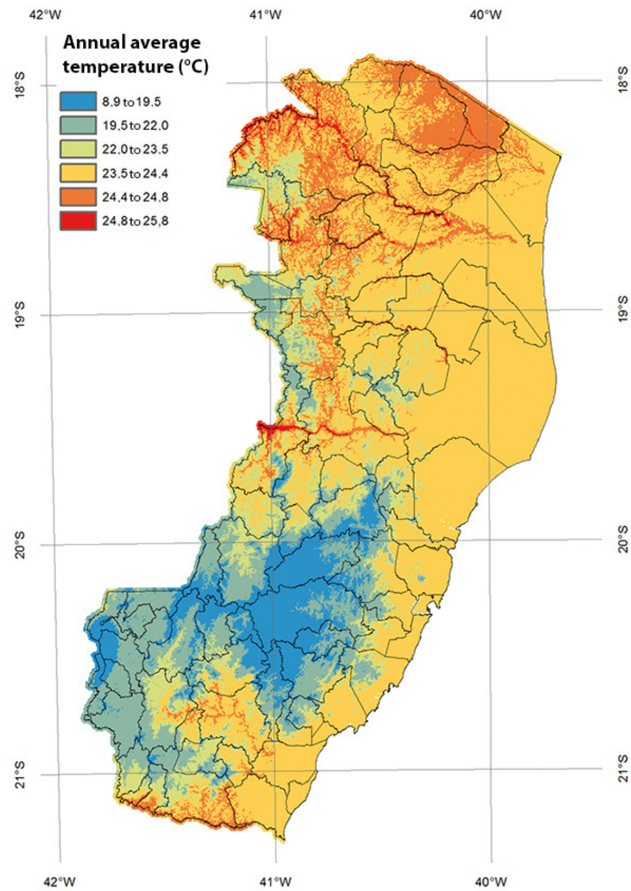

Figure 3. Spatial prediction of annual average temperature for the State of Espírito Santo.

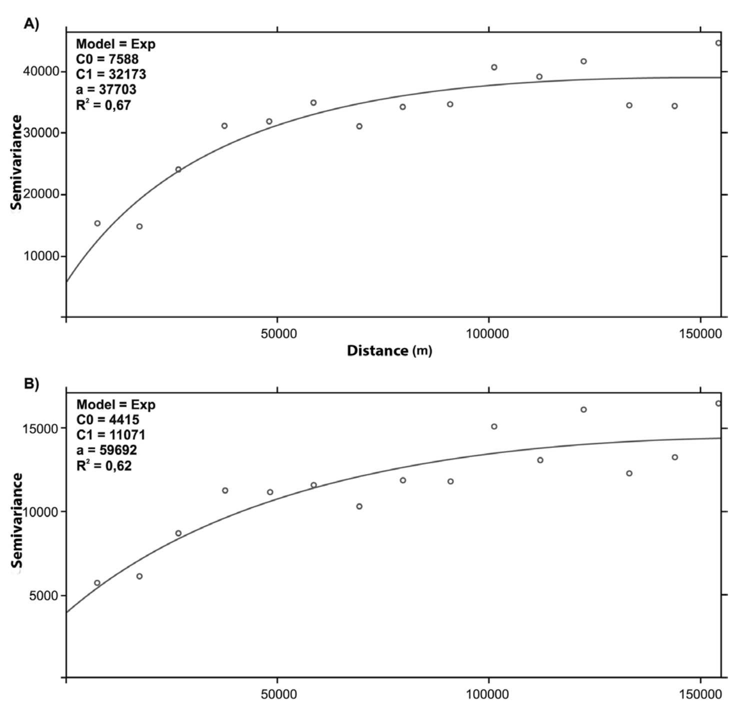

Figure 4. Experimental semivariogram adjusted for the prediction of the accumulated precipitation with 75% probability: (a) annual and (B) summer period (September to February).

Note: Exp: exponential; C0: pepita; C1: contribution; a: reach; R^2: coefficient of determination.

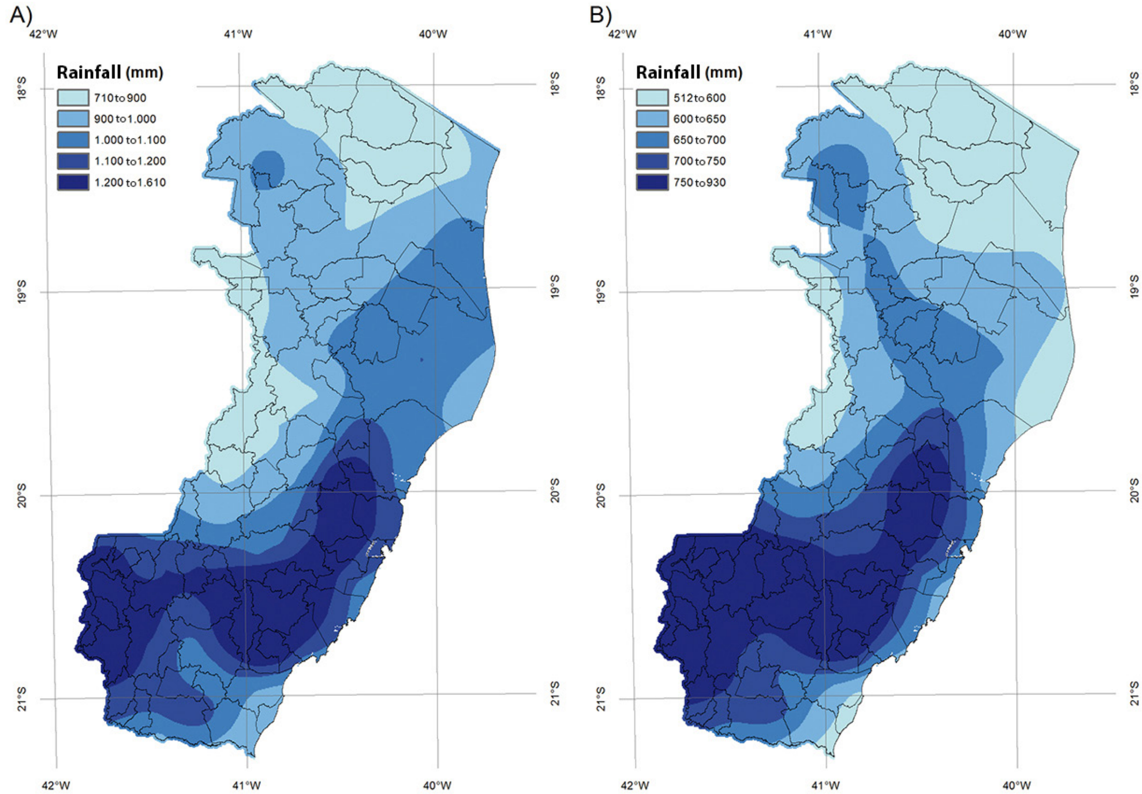

Figure 5. Spatial prediction of the accumulayed precipitation with 75% probability for the State of Espírito Santo: (a) annual and (B) summer period (September to February).

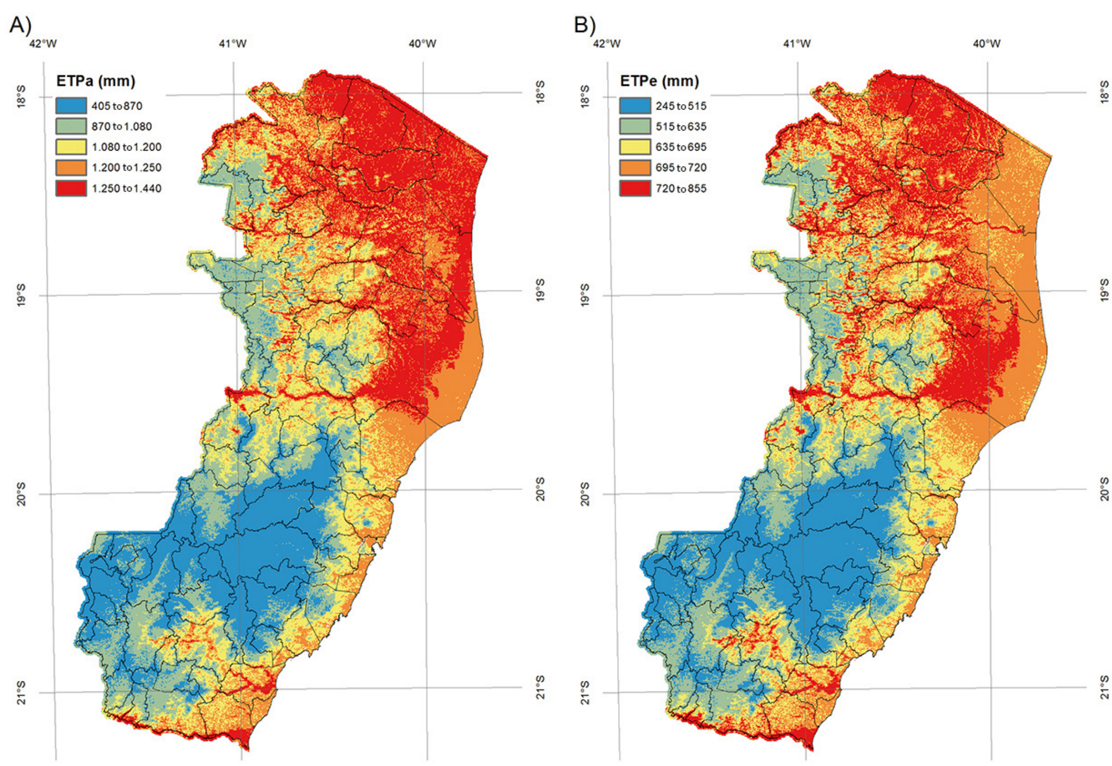

Figure 6. Potential evapotranspiration for the State of Espírito Santo: (a) annual (ETPa); B) summer period (ETPe).

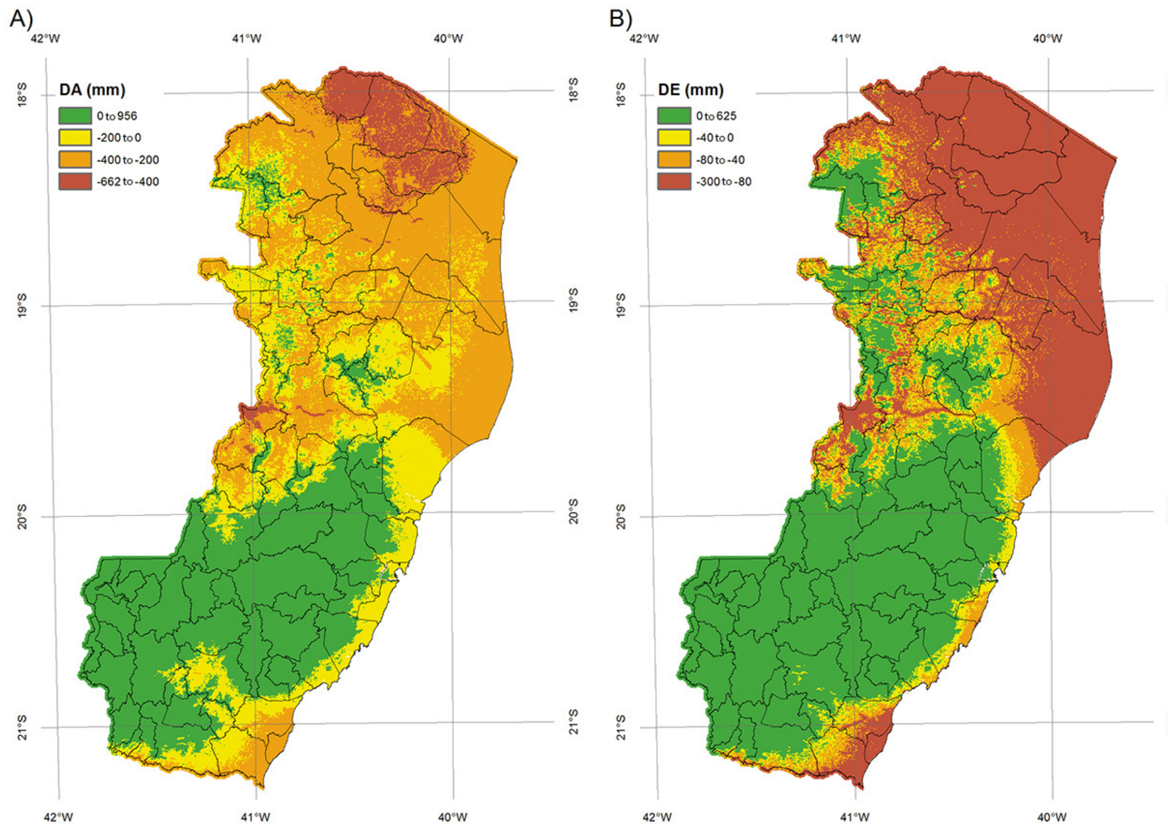

Figure 7. Water *deficit* for the State of Espírito Santo: (a) annual (DA); B) summer (DE).

The agroclimatic zoning shows that 74.3% of the territory of Espírito Santo presents aptness for the conilon coffee cultivation, and only 25.7 % feature thermal impediment, which confirms the natural vocation of the State for the production of this particular variety (Table 3). However, only 11.3% of the State area has high production potential and low climate risk, without annual water *deficit* and in the summer period. The greater part of the area (63.0%) has water restrictions, requiring the use of supplementary irrigation, mainly in the summer period (September to February).

Table 3. Area distribution between the aptness categories for conilon coffee cultivation in the State of Espírito Santo

Category	Area (km²)	%
Apt	5230.2	11.3%
Apt with light water restriction	7868.8	17.1%
Apt with moderate water restriction	5624.2	12.2%
Apt with severe water restriction	15525.8	33.7%
Water impediment	11829.3	25.7%
State Total	46078.3	100.0%

The greater part of the municipalities area with expressive production of conilon coffee, are located in the extreme north of the State, among them: Jaguaré, Nova Venécia, Vila Pavão, São

Mateus, Pinheiros and Boa Esperança, have severe water restrictions, and the use of supplementary irrigation is essential. The municipalities in the center-north region (Vila Valério, Rio Bananal, São Gabriel da Palha, Governor Lindenberg and Marilândia) have more favorable water conditions, with light and moderate water restriction (Figure 8).

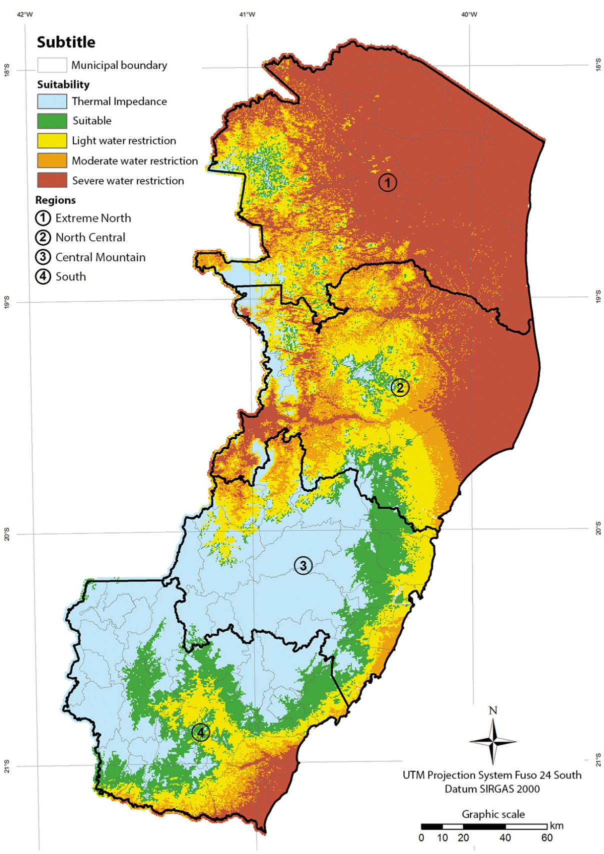

Figure 8. Agroclimatic zoning map for conilon coffee cultivation in the State of Espírito Santo.

5 FINAL CONSIDERATIONS

The modeling for the spatial prediction of average temperatures and annual and summer precipitatons, which are essential information for the agroclimatic zoning, showed to be suitable to the goal of the work. This evaluation was made based on the knowledge of the conilon coffee crops distribution in different climatic regions of the State. The densification of observation points (rain gauges and meteorological stations) can contribute to refine the predictive models of climatic variables, especially precipitation and agroclimatic zoning of that variety.

The conilon coffee has high potential for cultivation in the altitude ranges between 400 and 580 m, and can reach up to 670 m high, in the extreme northern region of the state. These areas are currently occupied, in their majority, by arabica coffee in a marginal manner. Thus, it is possible to implement conilon plantations in those areas not traditionally cultivated with this variety, but that are potentially apt and have restriction for the cultivation of arabica coffee.

The greater part of the area with thermal aptness for conilon coffee (approximately 85%) presents climate and water restrictions, requiring supplementary irrigation, under the perspective of productivity and reduction of climate risks.

In agroclimatic zoning, it was taken into consideration basically the macroclimate, by its compatibility with smaller scales, not allowing to contemplate more detailed climatic levels. Therefore, in addition to the macroclimate factors used in this work, it is necessary that, at a local level, the topoclimatic conditions (relief face) and the microclimate within the crop should be considered, making adjustments to the recommended aptnesses.

Regardless the agroclimatic apteness category, it is necessary to observe the existence of other environmental restrictions. Limitations related to soil, relief, water availability for irrigation, among others, may impose limitations on the implementation and conduct of conilon coffee plantations. The use of efficient conservation practices and correct soil and water management is indispensable for achieving the sustainable development of this activity.

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