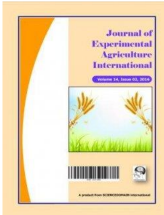

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Influence of Climate, Soil, Topography and Variety on the Terroir and on Coffee Quality

Samuel de Assis Silva[1*], Daniel Marçal de Queiroz[2], Nerilson Terra Santo[3] and Francisco de Assis de Carvalho Pinto[2]

[1] Department of Rural Engineering, Federal University of Espírito Santo, Espírito Santo State, Brazil.
[2]Department of Agricultural Engineering, Federal University of Viçosa, Minas Gerais State, Brazil.
[3] Department of Statistics, Federal University of Viçosa, Minas Gerais State, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors SAS and DMQ participated in the idea and management of the experiment, besides writing the article. All authors were responsible for tabulating and analyzing data. The authors FACP and NTS participated in the management of the experiment and the as well as in the bibliographic review. All authors read and approved the final manuscript.

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ABSTRACT

The study of *terroirs* is related to the understanding of a certain small territory, in which different local factors provide products with distinct qualities. This study had the objective to evaluate the influence of climatic, soil and topographic factors on the *terroir* and also on the quality of the coffee that is produced in these areas. The study was performed on two coffee producing *terroirs*. The climate's influence was evaluated regarding relative humidity, temperature, solar radiation and photoperiod. The soil at the *terroirs* was characterised based on its textural physical attributes and its formation and source material. The quality of the coffee was assessed through the analysis of its physical characteristics and sensory analysis. The results from the textural soil fractions were submitted to descriptive statistical analysis, followed by geostatistical analysis. They were also submitted to a separation test in order to identify significant differences in the various *terroirs*. The data were subjected to correlation analysis between quality and the variables that characterise the

**Corresponding author: E-mail: samuel.assilva@gmail.com;*

terroir. The data were also submitted to principal component analysis to describe the association of the variables. The soil's mineralogical and physical attributes did not differ between plantations, they did not exert an influence on coffee quality or the *terroirs* of production. Coffee quality is dependent on the *terroir*, and this, in turn, on the altitude, in plantation position and micro-climatic characteristics.

Keywords: Coffea arabica L.; precision agriculture; sensory analysis; speciality crops.

1. INTRODUCTION

The *Terroir* has been recognized as an important factor in the quality of cultivated products, mainly in cultivating grapes in European vineyards [1]. The study of *terroirs* is related to the understanding of a certain small territory, in which different local factors provide products with distinct qualities [2]. When under the influence of these factors, the products carry with them all the inherent characteristics of the elements that are themselves specific to the geographical area, thereby promoting their differentiation.

Directly, it can be said that the *terroir* is the combined effect of soil, slope orientation in relation to the sun, altitude, climatic features such as rain, wind speed, accumulated hours of sunlight, minimum, maximum and average temperature, at a given location where they are able to act on the nature and quality of the products grown at this location [3]. Van Leeuwen e Seguin [4] claim that these factors generally act jointly, however, in many situations it is possible to identify one or a few factors that act in isolation and that are therefore responsible for the differentiation of *terroirs*.

Studying the factors that, within a *terroir*, are crucial for the expression of a standard differentiable of the products is important, especially for production planning, a valorization of products grown and for exploring the potential of each region [5]. However, van Leeuwen et al. [1] state that it is difficult to study the effect of all the parameters of *terroir* in a single study, this is due to the multitude of factors and associations which act on the agricultural systems. Given these facts, many authors have evaluated the impact of a single parameter on the *terroir* and the quality of the products [1,3,4,6].

For Carey et al. [7], the *terroir* should initially be assessed on the basis of variables and attributes whose temporal variation is reduced or non-existent, such as topographical features and relief and physical soil properties, for example, and also by means of those which exhibit certain seasonality such as the micro-climatic conditions. Such evaluation provides information on the effects of the so-called natural *terroir* production that are defined by Vaudour [8] as being the fixed *terroir* unit, i.e. that which really characterizes a certain area and makes it different from another since there is no variation over the years.

For coffee cultivation, the notion of *terroir* has not been extensively explored and, consequently, the variables of these *terroirs* and their effects on the physical and sensory quality of the products have not yet been defined. Scholz [9], when evaluating the typology of coffee from Paraná, discussed the influence of *terroir* on the drink's quality, however, the author simply used the term without proper assessment of its effect. Various authors, however, have shown that coffee is highly influenced by altitude and average annual temperature at its production sites [10,11,12], however, none of these approached the idea considering the scope of the *terroir* concept.

Given this, the study presented here aimed to evaluate the influence of climatic factors, soil, topography and the varieties grown in the *terroir* and also in terms of the quality of the coffee produced in these areas as well as to understand how the *terroir* influences the coffee plant's behavior.

2. MATERIALS AND METHODS

The study was conducted during the 2010/2011 harvest at four plantations located in the municipal area of Araponga, in the Zona da Mata region in Minas Gerais State, Brazil, located at 20° 40' South latitude and 42° 31' West longitude.. The plantations were thus identified: (A) JA_B (Lower João Andrade Farm); (B) Braúna (Braúna Farm); (C) JA_A (Upper João Andrade Farm) and (D) Serra do Boné (Serra do Boné Farm).

The study was performed in two *terroirs* of coffee production as defined by Silva et al. [13], which are located at different altitudes and encompass a number of distinctive farms (Table 1).

The Serra do Boné *terroir* covers 8.5 hectares with strong rolling mountainous relief and a large difference between the lowest and highest points. This area has been cultivated for decades with coffee, however, the current crop is 6.5 years old, during the first 4 of these years there was an organic system of cultivation. Currently, the area is going through a process of change to the conventional system, but only with the use of mineral fertilizers.

Table 1. Coffee producing *Terroirs* in Araponga – MG

Terroir	Farms	Altitude	
		Minimum	Maximum
1	Serra do Boné	1090	1270
2	Braúna, JA_B e JA_A	860	1090

The other farms that make up the second *terroir* jointly cover a 39 ha area. Despite its rolling relief the landscape, features of these are smoother than the first. This *terroir* has been cultivated, as with the first, for several decades with coffee, the current crop is the oldest with a cultivation period of 13 years while the youngest is only 4 years old. The adopted cultivation system in this *terroir* is the conventional system with the sporadic use of pesticides for controlling pests and diseases.

The soil from both *terroirs* was classified, according to Embrapa [14], as typical dystrophic Red Yellow Latosol, its texture being clayey to very clayey and its A horizon was classified as moderate.

The coffee varieties grown in the two *terroirs* are the same, predominantly catuaí and catucaí, both with red colored fruits. Only the Serra do Boné *terroir* has yellow colored fruit varieties, with a part being the yellow catucaí variety and part the yellow bourbon variety.

In order to evaluate the influence of climate on the *terroirs* and on coffee quality, automated weather stations (model - MicroDaq Onset HOBO, New Hampshire, USA) were used. These meteorological stations were positioned at strategic locations and represent each one of the studied plantations. They measured relative humidity (%), temperature (°C) and solar radiation ($W.m^{-2}$) at 1-minute intervals during recording periods. The station's recording period was 14 months, which comprised the last three phases of the coffee plant's reproductive cycle (Graining, Fruit Maturation and Resting, and Branch Senescence) and the first phase of the vegetative period (Vegetation and Flower Bud Formation).

The soil from the *terroirs* was characterized based on its physical textural attributes and regarding its formation and source material through mineralogical analysis of the clay fraction.

In order to map soil texture, samples were collected, from each of the four farms, in 0-0.20 m soil layers in an uneven mesh with 150 sample points, and the geographical coordinates of each sample point was set with the aid of GPS topography.

Textural composition was determined through the pipette method, using NaOH solution as the dispersant chemical and mechanical agitation in low rotation apparatus for 12 hours, in accordance with the methodology as proposed by Embrapa [15]. The clay fraction (CLAY) was separated by sedimentation, in accordance with Stokes' law, and silt fraction (SILT) was determined by difference. The sand fraction was subdivided into coarse sand (CS) and fine sand (FS), the separation was performed using sieves with distinct mesh.

In order to determine soil mineralogy, samples were randomly collected in layers of 0-0.20m from each plot at each plantation that was involved in the study, 15 soil sub-samples of which were homogenized so as to compose a composite sample representative of the plot. Mineralogy determination was only performed on the clay fraction for the purpose of soil characterization of the farms and consequently of the *terroirs*. The samples were prepared and irradiated with x-rays in a Philips diffractometer using copper tubing, in accordance with the methodology presented by Jackson [16]. After this analysis, the x-ray diffractograms were constructed and interpreted for each farm and *terroir,* in order to determine the predominant mineral type.

So as to determine the coffee drink's quality from each plot at each farm, during the harvesting period approximately 30 plants per hectare, chosen randomly, were sampled. In each plant, cherry fruit from four branches, one pair from each side of the plant facing the lines, were collected by hand. The choosing of these branches was done randomly so that these fruits would be representative of the plant. The collected fruits were later grouped together, forming a composite sample per plot.

Fruit samples were peeled, then artificially dried with 40°C air temperature, until they reached a water content of approximately 12% b.u, using a fixed bed sample dryer in trays, with a gas burner. The dried samples were processed and then packed in plastic containers and stored for a period of approximately two months before the completion of physical and sensory quality test, this being known as the beverage test.

The beverage test evaluated characteristics such as sweetness, flavor, acidity, body, balance and overall quality. The analyses were performed in accordance with the national and international competition rules from the Specialty Coffee Association of America - SCAA and according to their sensory evaluation of coffee form.

The results obtained from the soil textural analysis for each of the farms and *terroirs* were subjected to descriptive statistical analyses. In order to verify the data likely to be considered as outliers, the upper and lower quartiles were analyzed and the test Shapiro-Wilk's was performed to test normality at 5% probability (W).

Subsequently, the data were subjected to geostatistical analysis, this was done in order to verify the existence and, in this case, to quantify the degree of spatial dependence, from the theoretical function adjustments to experimental variogram models, based on the assumption of intrinsic stationarity hypothesis, as in the equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)^2]$$

where, *N (h)* = is the number of pairs of experimental observations and *Z (xi), Z (xi +h)*, separated by a h vector.

In the adjustment of theoretical models to experimental variograms, the nugget effect coefficients (C_0), landing (C_0 + C_1), structural variance (C_1) and scope (a). The models tested for adjustment were spherical, exponential, Gaussian and linear. The choice of models was made based on the criterion of least-squares, which was opted for in the selection of models with the highest R^2 value (coefficient of determination), the least SSR (sum of the square of the residue) and the highest correlation coefficient value obtained through the cross-validation method.

Spatial dependence having been proven, it was estimated, in non-sampled sites, soil texture values, the maps of spatial distribution already having been made, using ordinary kriging.

The results obtained from the textural soil analysis were still submitted to a separation test so as to identify the significant differences between the average values of each farm. The t test was used for independent samples, at 5% probability, considering the null-hypothesis, there is no significant difference between mean treatments.

Pearson's correlation analysis was used to test the hypotheses of this study. The correlation between the quality attributes (overall quality, sieve, sweetness, flavor, acidity, body and balance) and the natural *terroir* variables (Geospatial position – x and y, and altitude of the sampling points, levels of thick and thin sand, silt and clay) was assessed.

Principal component analysis (PCA) was still used to generate a new variable (component) that describes the association of natural *terroir* variables. PCA was performed based on the existing correlation matrix between the components and the actual data, in order to identify new variables that explain the majority of the variability.

When selecting the number of principal components, the components associated with eigenvalues above 1 were used. In the event of there being a correlation of the components with the chemical soil attributes, the values exceeding ± 0.7 were considered significant, as suggested by Zwick e Velicer [17] and used by Silva e Lima [18].

After selecting the number and the principle components, an analysis of correlation was performed between quality attributes and component (s) so as to assess which natural *terroir* variables represent the variability of quality and consequently are more decisive in expressing such quality.

3. RESULTS

The descriptive statistical analysis results of textural soil fractions from the farms involved in the study are presented in Table 2. Measures of central tendency (mean and median) are closed for all the fractions in all the farms studied. This fact indicates symmetry in the distribution of data, which is confirmed by the asymmetry coefficient values being close to zero. Based on the kurtosis coefficient, which shows the dispersion of the distribution in relation to a normal curve, the fractions showed a platykurtic distribution, but with smooth flattening in relation to the normal distribution curve, once these values are close to zero.

The textural fractions CS and CLAY presented spatial dependence in all the farms while the fractions FS and SILT only presented spatial dependence at the JA_A farm, according to the variogram results that are presented in Table 3. These results corroborate with those found by Silva et al. [19] which indicated that, generally speaking, with the exception of SILT, textural fractions do not randomly vary, but follow well-defined spatial patterns that are generally influenced by the terrain's slope.

The exponential, spherical and Gaussian models were adjusted to the textural fractions The model that fit best was the exponential one, adjusted to 60% of the fractions that showed dependency. The second best was the spherical model that adjusted to 30%, whereas the Gaussian model adjusted to 10% of the fractions. The models' coefficient of determination values ranged from 70 to 96.9% with most being values above 90%.

The largest ranges were observed for CS and CLAY, this being highlighted in the Serra do Boné farm where the range for CS was 280 m and was 140 m for CLAY. The greatest variability was observed for SILT at the JA_A farm, corroborating the results that were obtained in the CV% descriptive analysis, where this was higher for this fraction.

The SDI, according to the classification as proposed by Cambardella et al. [20], was elevated for the CS and CLAY textural fractions at the JA_B farm and for SILT and CLAY at the JA_A farm. The other fractions that presented moderate SDI had intervals ranging from 55 to 73%. Gonçalves e Folegatti [21] found average variability for these fractions, while Silva et al. [19] found elevated variability.

Table 2. Descriptive statistics of the textural fractions; coarse sand (CS), fine sand (FS), silt (SILT) and clay (CLAY) for the four farms involved in the study

Textural fractions	Mean	Median	Minimum	Maximum	CV‡	Cs‡	Ck‡	w‡
				Braúna				
CS†	80.18	74.12	36.48	151.26	32.36	0.84	-0.55	*
FS	161.34	156.82	82.15	264.32	24.56	0.35	-0.53	ns
SILT	194.75	192.31	0.00	414.51	44.64	0.45	-0.55	ns
CLAY	553.20	569.36	362.69	748.13	16.07	-0.17	-0.53	ns
JA_B								
CS	85.11	80.75	15.85	151.62	34.31	0.25	-0.52	ns
FS	134.16	134.25	19.47	198.92	29.10	-0.42	-0.24	ns
SILT	183.02	177.83	0.00	396.83	47.52	0.15	-0.43	ns
CLAY	591.11	598.80	344.83	780.31	16.54	-0.18	-0.41	ns
JA_A								
CS	144.68	142.73	52.69	280.80	38.71	0.44	-0.62	*
FS	199.20	192.27	91.69	321.95	28.05	0.16	-0.50	ns
SILT	105.35	99.01	0.00	244.50	48.49	0.60	-0.20	*
CLAY	524.12	518.23	368.81	711.89	14.71	0.19	-0.57	ns
Serra do Boné								
CS	119.90	118.74	62.56	183.61	20.79	0.03	-0.31	ns
FS	146.31	143.20	71.14	211.21	19.34	0.04	-0.02	ns
SILT	228.62	236.13	27.55	389.32	34.10	-0.34	-0.11	ns
CLAY	491.38	491.16	360.58	603.86	11.37	-0.08	-0.30	ns

*† CS, FS, SILT and CLAY in $g.kg^{-1}$; ‡ CV% -coefficient of variation; Cs – symmetry coefficient; Ck-kurtosis coefficient; ns -normal distribution by the Shapiro-Wilk's test ($p < 0.05$); * - non-normal distribution by the Shapiro-Wilk's test ($p < 0.05$)*

Table 3. Models and parameters of the mean variograms adjusted to textural fractions for the farms under study. Parameters: EPP – pure nugget effect; C0 - nugget effect; C0+C - landing; SDI - spatial dependency index (C/C0 + C); a - range; R2 - variogram model coefficient of determination; R2 (VC) - cross-validation coefficient of determination

Textural fractions	Model	C_0	C_0+C	a	SDI	R^2	R^2(VC)	p-valor
				Braúna				
CS[†]	Exponential	206.00	756.40	78.30	27.00	78.00	28.31	0.00000
FS	EPP	-	-	-	-	-	-	-
SILT	EPP	-	-	-	-	-	-	-
CLAY	Exponential	3200.00	11050.00	61.00	28.00	85.00	30.11	0.00000
JA_B								
CS	Exponential	237.00	2885.00	40.20	08.20	70.00	26.20	0.00000
FS	EPP	-	-	-	-	-	-	-
SILT	EPP	-	-	-	-	-	-	-
CLAY	Exponential	460.00	11180.00	60.00	04.10	90.40	24.10	0.00000
JA_A								
CS	Spherical	1617.00	3495.00	147.00	44.00	90.00	24.50	0.00000
FS	Exponential	696.88	3227.00	44.00	22.00	94.00	25.50	0.00000
SILT	Spherical	79.55	2331.00	29.60	03.40	92.40	25.10	0.00000
CLAY	Spherical	720.00	7301.00	118.10	09.90	96.90	50.10	0.00000
				Serra do Boné				
CS	Gaussian	370.00	880.00	280.00	40.00	84.00	27.80	0.00000
FS	EPP	-	-	-	-	-	-	-
SILT	EPP	-	-	-	-	-	-	-
CLAY	Exponential	1078.00	2357.00	140.00	45.00	73.00	24.40	0.00010

[†] CS, FS, SILT and CLAY in g/kg;

Figs. 1, 2, 3 and 4 show thematic maps of the spatial distribution for the textural fractions that presented spatial dependence for each of the farms involved in this study.

It was observed that, in every farm, the inverse and characteristic behavior of clay and sand fractions is evident, mainly depending on the slope, since there is a trend in the concentration of clay in the upper portions of the areas and the concentration of sand on the lower portions. This behavior is usually caused by surface runoff in regions with rugged relief, contributing to the solid particles being washed down the slope.

Comparatively analyzing the farm maps, among these maps relevant value and amplitude variation are not noted for the CS and CLAY fractions, and consequently, it is the same between the two *terroirs*. This fact is evident when looking at the results for the separation test as shown in Table 4, which shows that there is not, with the exception of the CS, a significant difference between the farms as regards textural fractions.

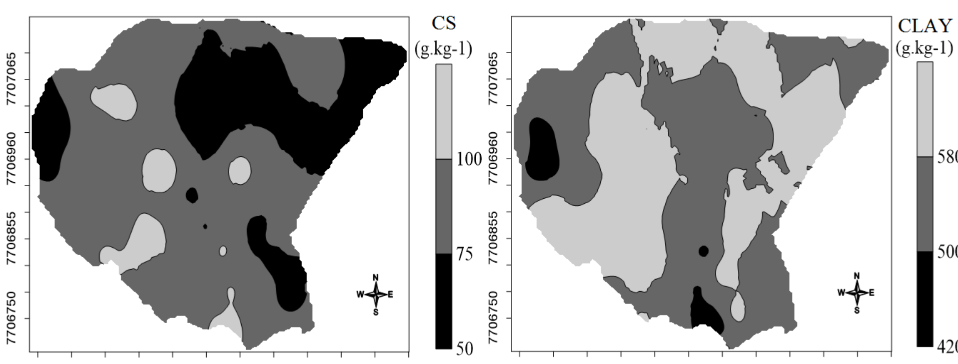

Fig. 1. Spatial distribution maps of the CS and CLAY textural fractions at the Braúna farm

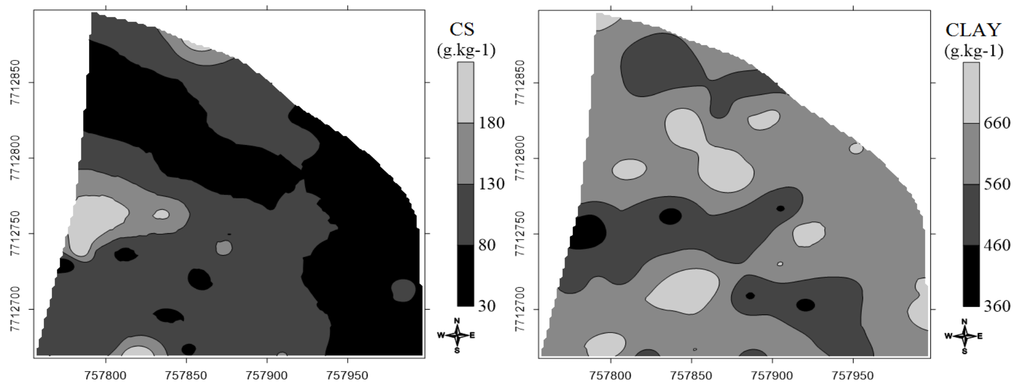

Fig. 2. Spatial distribution maps of the CS and CLAY textural fractions at the JA_B farm

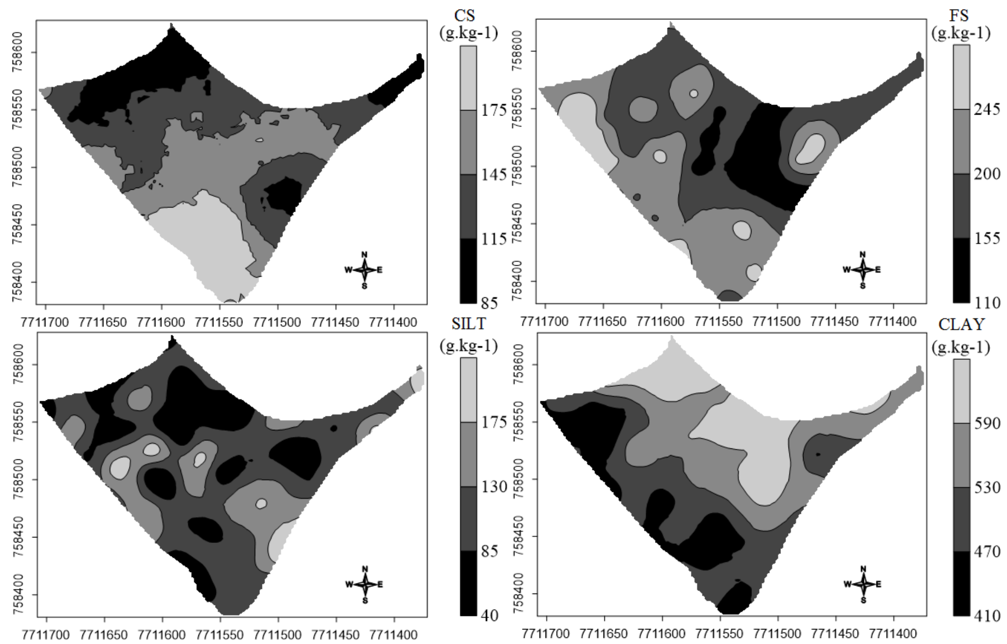

Fig. 3. Spatial distribution maps of the CS, FS, SILT and CLAY textural fractions at the JA_A farm

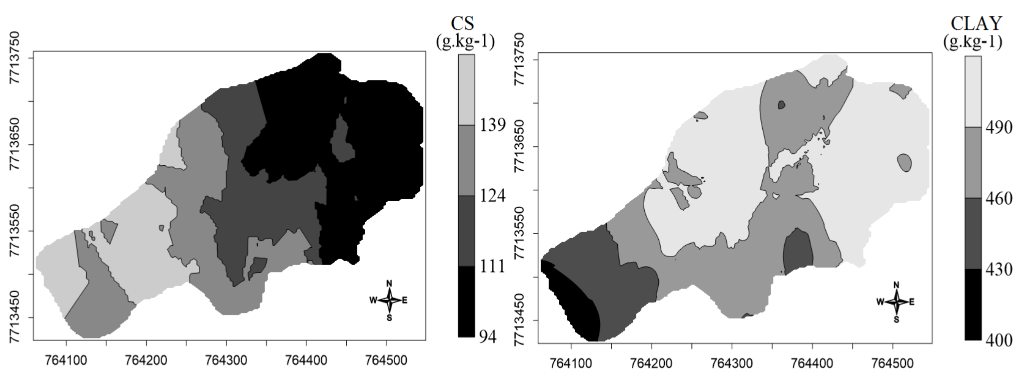

Fig. 4. Spatial distribution maps of the CS and CLAY textural fractions at the Serra do Boné farm

Table 4. Difference between the quality variable averages for the farms involved in the study and for the two coffee producing *terroirs* in Araponga, Minas Gerais

Farms	Textural fractions			
	CS[†]	**FS**	**SILT**	**CLAY**
Braúna	80.18[‡] ± 25.94	161.34 ±39.62	194.75 ±86.94	553.20 ±88.90
JA_B	85.11 ±29.20	134.16 ±39.04	183.02 ±86.97	591.11 ±97.77
JA_A	144.68 ±56.01	199.20 ±55.87	105.35 ±51.08	524.12 ±77.09
Serra do Boné	119.90 ±24.93	146.31 ±28.29	228.62 ±77.95	491.38 ±55.87
Terroir 1	103.32 ±28.34	164.90 ±38.23	161.04 ±74.12	562.14 ±80.97
Terroir 2	119.90 ±27.10	146.31 ±32.57	228.62 ±76.04	491.38 ±77.54

[†] CS, FS, SILT and CLAY in g⁄kg; [‡] Significantly different at P<0.05 according to t test. Mean ± standard error (S.E.). D.F. = 3.

Soil mineralogy, analyzed by x-ray diffractograms of the clay fraction, (Fig. 5) showed a predominance of kaolinite group minerals at all of the farms. Kaolinite is one of the most commonly found minerals from clay fractions in tropical soils [22] especially those originating from magmatic rocks [23]. In Brazilian soil this is the predominant mineral [24,25].

Despite there not being any significant differences between the textural fractions and between the soil mineralogy of the farms involved in the study and consequently between the coffee producing *terroirs*, a Pearson linear correlation analysis was used to find any relationship between these variables and the areas' topographical features with the variables that measure the coffee quality. The results of this analysis are presented in Table 5.

According to van Leeuwen e Seguin [4], who claim that the factors that make up a *terroir* usually act jointly on the existing variation between units, a principal component analysis was used (Tables 6 and 7) so as to study the possible integration of topographic variables, the position and the attributes of soil on coffee quality and consequently on the *terroirs*.

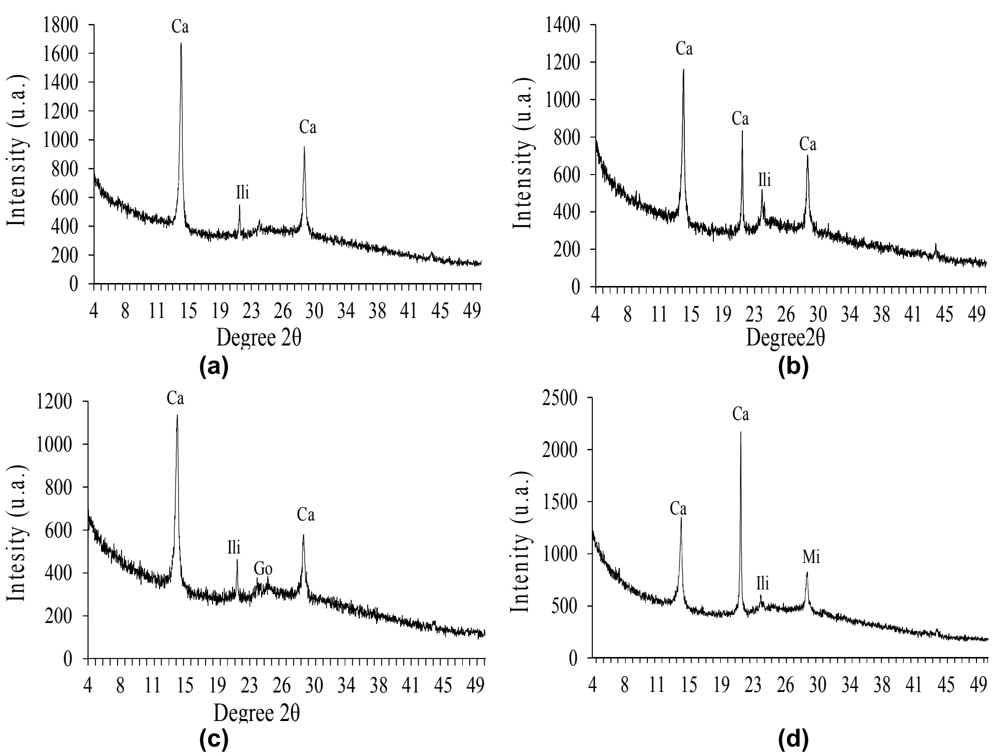

Fig. 5. X-ray diffractograms of the clay fraction from the farms: (a) Braúna; (b) JA_B; (c) JA_A, and; (d) Serra do Boné. Ca – kaolinite; Ilita – Illite; Go – Goethite; Mi – Talc (Mica)

During the principle component analysis three components were extracted, which cumulatively explain approximately 91.54% of the total data variability and that, in accordance with the selection criteria used in this study, show an eigenvalue equal to or greater than one. The other components, in addition to presenting low individual contribution that explains the data's variability, have an eigenvalue less than one and, therefore, were not considered in the subsequent analyses.

Table 6 presents the weights that are assigned to the variables that characterize the *terroirs* for each principle component generated. The first component presents elevated and significant weights (exceeding ± 0.7) for the X, Y coordinates and for the Altitude of the sampling points with values ranging from -0.86 to -0.96. The second component provides significant weight only for the FS (-0.9186) while the third only for the CLAY (-0.7091). In this way, one could say that the first principle component jointly represents the factors related to geographical location and land topography, while the second component represents isolated information from FS and the third from CLAY.

The weights obtained for each of the three major components were correlated with quality attributes, this is done through the Pearson linear correlation analysis, the results are presented in Table 7.

Table 5. Pearson linear correlation between the geographical coordinates, altitude and textural soil fractions and the coffee quality attributes

Variables	Quality's variables						
	Physics	Global	Honey	Flavor	Acidity	Body	Equilibrium
X	-0.22	0.44*	0.53*	0.34	-0.14	-0.02	0.45*
Y	-0.16	0.32	0.45*	0.25	-0.23	-0.02	0.33
Altitude	-0.09	0.39	0.47*	0.28	-0.20	0.05	0.44*
CS	0.24	0.09	0.17	-0.11	0.12	-0.12	0.17
FS	0.36	0.03	-0.18	-0.16	0.43	-0.07	0.18
SILT	-0.73*	0.13	0.18	0.20	-0.14	0.05	0.08
CLAY	-0.05	-0.21	-0.09	-0.08	-0.25	0.09	-0.32

** Pearson linear correlation significant ($p < 0.05$)*

Table 6. Weights assigned to the variables that characterize the *terroirs*, in the principle components' composition

Variables	Components		
	CP1	CP2	CP3
X	-0.9450*	0.2619	-0.0480
Y	-0.8616*	0.2747	-0.3768
Altitude	-0.9581*	0.0467	-0.1336
CS	-0.6017	-0.4503	-0.1413
FS	-0.1738	-0.9186*	0.1549
SILT	-0.2295	0.6777	0.6680
CLAY	0.5881	0.3551	-0.7091*

** Pearson linear correlation significant ($p < 0.05$)*

Table 7. Correlation analysis between the principal components and the quality attributes

Variables	Components		
	1	2	3
Global Quality	-0.47*	0.09	0.03
Physical Quality	0.08	-0.35	-0.26
Honey	-0.74*	0.26	-0.11
Flavor	-0.23	0.26	0.03
Acidity	0.07	-0.42	0.22
Body	0.04	0.10	-0.02
Equilibrium	-0.43*	-0.04	0.07

** Pearson linear correlation significant ($p < 0.05$)*

The second and the third component are not correlated with any of the quality attributes, confirming what was previously discussed - there was no observed influence of textural fractions on coffee quality or the *terroirs*. In contrast, the first principle component presented significant correlation with the coffee's overall quality and with the drink's sweetness and balance. This indicates that the quality, expressed by its overall rating, is influenced by the plantation's location and altitude, as well as the *terroirs,* since these mainly differentiate in terms of the drink's sweetness and balance, as discussed by Silva [26].

The "mesoclimate" is also a potential factor for introducing nuances in coffee's sensory characteristics. To this end, temperature values (Fig. 6), relative humidity (Fig. 7) and daylight hours (Table 8) were analyzed in terms of coffee phenology, this was done so as to study their effects during each of the phases covered by the study.

The farms that comprise the first *terroir* (Braúna, JA_B and JA_A) had very similar average temperatures during all the phenological phases that were covered by the study. When compared to the second *terroir* (Serra do Boné), their average values were considerably higher, since this had an average temperature that was below 20°C at all study phases and the difference, when compared to the other farms, was around 2°C.

Regarding the maximum and minimum temperatures, the Serra do Boné *terroir* had the lowest temperature, which was observed during the fifth phenological phase which corresponds to the fruit maturation phase. At that stage the *terroir* was also observed as having the highest thermal amplitude between day and night (21.02°C). This large temperature difference between day and night is ideal for slowing coffee maturation, which tends to generate higher quality and generally sweeter products, since the greatest sugar accumulation and distribution is benefited by a reduced maturation speed [27].

At the other *terroir,* the highest amplitude was observed at the Braúna farm (20.92°C – phase1)

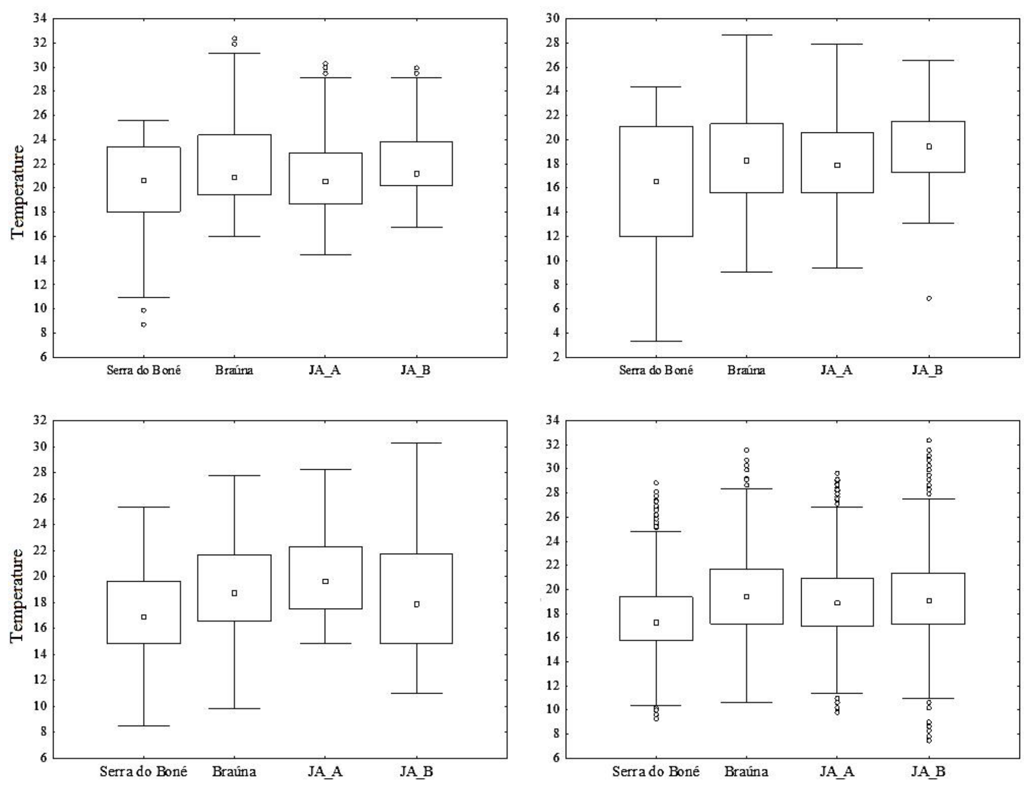

Fig. 6. Temperature frequency distribution (°C) for the four phenological phases (a – graining; b – fruit maturation; c – senescence; d – floral bud formation) at each plantation

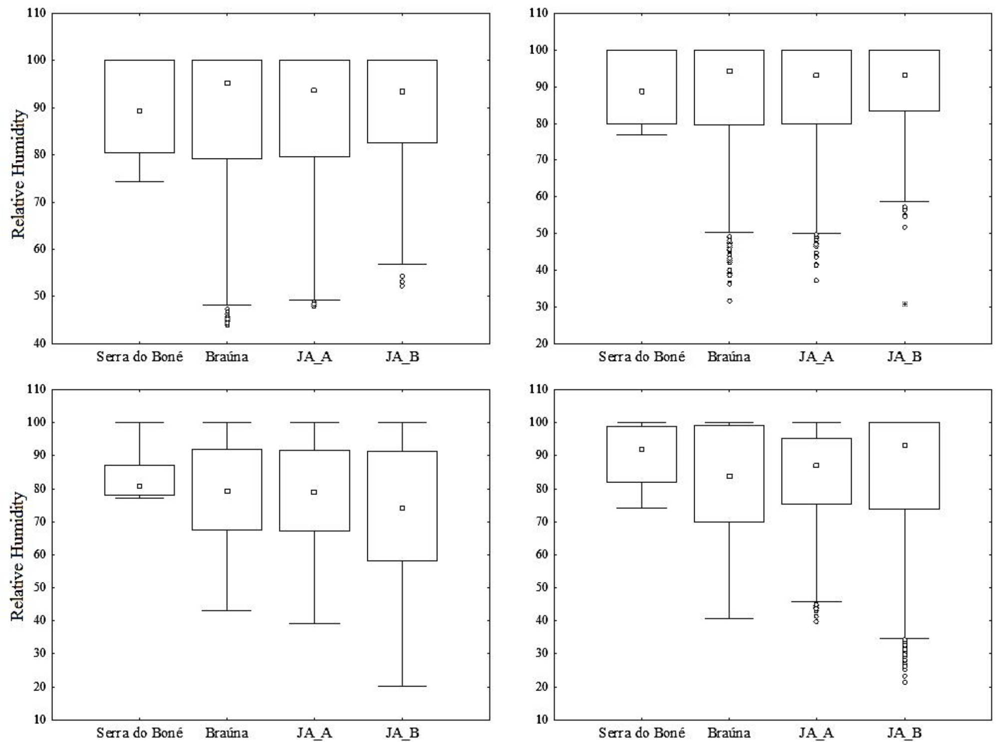

Fig. 7. Relative humidity frequency distribution (%) for the four phenological phases (a – graining; b – fruit maturation; c – senescence; d – floral bud formation) at each plantation

Table 8. Average number of natural daylight hours for the four phenological phases covered by the study at each of the plantations

Farms	Phenological phases			
	4ª	**5ª**	**6ª**	**1ª**
Braúna	12.67	11.19	12.00	12.30
JA_B	12.50	11.30	11.00	14.64
JA_A	12.59	11.80	12.00	12.48
Serra do Boné	13.00	12.00	12.00	15.00

and the lowest at the JA_A farm (13.39°C – phase 6). Despite the higher amplitude at this *terroir* being very close to that observed at the Serra do Boné *terroir*, the minimum and maximum temperatures were higher, which from the point of view of specialty coffee production is not very ideal, mainly for the phase in question, corresponding to the flower bud formation phase.

At the Serra do Boné *terroir,* moisture distribution is closer to normal, without any major fluctuations during the phenological phases. This same behavior was not observed at the other *terroir*, where the distribution varied greatly from the data's normalcy. An explanation for this could be the fact that the Serra do Boné farm is located in an area curtailed by woods, which tends to maintain a higher minimum humidity.

When one analyzes the average number of hours of natural daylight (Table 8), it is observed that, with the exception of the 6th stage phenology (resting phase and senescence of branches), the Serra do Boné *terroir* receives more hours of solar radiation, primarily during the first phase (vegetation and flower bud formation).

4. DISCUSSION

Upon analyzing the Shapiro-Wilk's test results, ($p<0.05$) it was observed that the CS fractions from the Braúna farm and the CS and SILT fractions from the JA_A farm were far from normalcy. This fact would be a hindrance in performing some analyses that have as a requirement data normalcy as a restrictive factor. Cressie [28] claims that normalcy is not a requirement of geostatistics, however it is convenient that the distribution does not show lengthened extremities, which could compromise the analysis. For the case in question, despite the absence of normalcy for those fractions, they did not show elongated distribution, as justified in their asymmetry values.

The coefficient of variation (CV), according to the classification as proposed by Warrick e Nielsen [29], performed within the 12 to 60% variation range for all fractions in every farm, this being classified as average variation. The greatest variations were observed in SILT, which, according to Silva et al. [30] among other factors, is mainly because of its method of determination by difference, due to the risk of error in the analyses that are embed in this fraction and consequently through the incorporation of existing variability in sand and clay in this fraction.

On the basis of the average proportion values of CS + FS, SILT and CLAY, and based on the identification model of the textural classes of soil samples (textural triangle) as presented by Embrapa [14], there is no difference between the soil texture from the four farms, since it is possible to classify the soil profile as being clayey in texture for all of them.

At the Braúna farm there is a continuous strip formation with high concentrations of clay surrounding the plantation almost from one end to the another. This could be a feature of plantation convex land-form with its "half an orange" shaping, which favors water divergence and consequently the deposition of materials that are carried by rainwater through laminar erosion.

Because the JA_A farm sits on a flat land-form area, slope influences are more noticeable in the distribution of textural fractions. In this type of area, according to Bertoni e Lombardi Neto [31], runoff happens in a balanced manner, following the one-way slope. For these authors, the runoff effect, despite being evident in almost all sloping regions, are not always cause for concern from an environmental point of view, because damage is dependent on each area's conditions. Silva et al. [30] reported that, as the clay fraction is directly related to cohesion, aggregate stability and soil permeability, areas that have high clay levels tend to be more cohesive and more structurally stable, reducing the erodibility due to low aggregate instability.

For silt at the JA_A farm, its spatial distribution strengthens the previously discussed idea for this fraction. The formation of small "bubbles" within larger areas of the map demonstrate its greatest variability and the difficulty to draw conclusions from it. In addition, silt is a fraction of little relevance when studying soil physics [32], since, despite it being a powder such as clay, it has no appreciable cohesion, it does not present relevant plasticity when wet and is devoid of any load.

When the separation test was performed among only the two *terroirs*, no significant difference was observed for any of the textural fractions. Given this, it can be affirmed that, although important for crop production [33], textural fractions did not have, separately, an influence on the *terroirs* in Araponga – Minas Gerais, with all farms and units having similar behavior.

As mentioned earlier, there is a predominance of kaolinite in the mineralogical composition of the soil of the two terroirs. The kaolinitic soils have a higher capacity for particle adhesion and cohesion, due to the possibility of face-to-face adjustment in this clay mineral [34]. From the chemical view, as this mineral has a variable load, the natural range of the soil's pH (4 to 7.5) presents a predominance of negative loads [35].

The farm's soil at the Serra do Boné *terroir* has faint traces of mica in its composition, which can be explained by the much closer proximity of the rock matrix, given that it is a rocky region and the plantation is located right next to it. Melo et al. [25] state that micas contribute to greater plasticity and tackiness of clay, however they are less expansive. From a chemical point of view, the authors claim that this clay mineral is only able to exchange cations with the soil solution when its decomposition occurs, there being stronger links to other minerals such as montmorillonite, for example.

Despite its presence on the soil at the Serra do Boné *terroir*, the traces of mica that were found are not proportionally significant in relation to the kaolinite, having a low influence on the clay characteristics and consequently on the area's cultivated plants. Melo et al. [24] state that for highly weathered soils in tropical regions, the presence of large concentrations of primary minerals, such as mica, is not common and when these are present, their influence on the clay's quality of is insignificant.

When looking at the results from Table 5 one can see that there is, in fact, an isolated and direct relationship between the soil and quality attributes, with the exception of the SILT that presented a significant inverse correlation with the fruits' size (characterized by the sieve). However, this correlation is not justifiable and a little inexplainable, since this textural fraction is devoid of load and is considered an inert material in the soil. In addition, it is also the fraction that is most susceptible to determination error since it was not directly measured but rather determined by difference.

Geographical coordinates (X and Y) and altitude were the variables that correlated most with quality attributes, especially with the drink's sweetness and balance. These results highlight an individual relationship of these variables with these quality attributes.

Several authors have commented on the positive effect of altitude on overall coffee quality [10,11,12,36], however the results obtained in this study show that the joint action of this and the plantation's position influence not only the overall quality, but also the attributes that differentiate drinking patterns, and is therefore fundamental in defining *terroirs*.

Zsófi et al. [6], in a study on vine, stated that, among the many factors that determine the quality of the grapes, the altitude and position of the grapevine are what most influences the *terroirs.* Carey et al. [7] state that this occurs because these variables show greater continuity when compared to others with greater variability, which results in a more homogeneous influence along the landscape.

In the climate variables, the larger photoperiod, as with what happened with the Serra do Boné *terroir*, is a desirable thing, since a greater number daylight hours represents a more active photosynthetic activity and consequently a smaller loss of yield and fruit quality since the plant is able to recover more quickly. Nascimento et al. [36] states that between 09:00 and 14:00, when light intensity is greater, there is a reduction in carbon assimilation, this is probably due to the stoma closing which is initiated by water loss in these conditions. During this phase the coffee plant's photosynthetic rate is reduced, and only increases after this period along with the reduction of light intensity to adequate levels and subsequently reopening the stoma. From this moment on, with the natural reduction of luminous intensity up until the full sunset, the photosynthetic rate also decays due to decreased light supply. In situations such as those observed at the Serrado Boné *terroir*, photosynthetic peaks tend to be more prolonged, due to the observed increased photoperiod.

Generally speaking, the Serra do Boné *terroir* has a well-suited micro-climate, different from that observed at the other *terroir*, with more suitable climatic conditions for specialty coffee production, mainly from a temperature and photoperiod point of view. This flavours, among other factors, sugar accumulation in raw grain, due to more uniform maturation, culminating in the drink being sweeter. It can be affirmed that the micro-climate, as well as having an influence on coffee quality, also influences the *terroirs*.

Van Leeuwen et al. [1], while studying the effect of climate, soil and cultivation on a grape producing *terroir*, found that climatic effect is critical to understanding and defining *terroirs*. These authors state that this happens because the weather has an intimate and direct connection with the culture site insertion and significantly influences any agricultural planting.

5. CONCLUSION

The mineralogical and physical attributes of the soil did not differ between the plantations studied, excluding their effect on coffee quality and the producing *terroirs* in Araponga – Minas Gerais.

Coffee quality, expressed by its overall rating, and the *terroirs*, which were mainly distinguished on the basis of the drink's sweetness and balance, are influenced by the location and altitude of the production site and its quality depends on the *terroir*, and this in turn, by the plantation's altitude and position.

The Serra do Boné *terroir* has a well-suited micro-climate and is different from that observed at the other *terroir*, with more suitable climatic conditions for specialty coffee production, mainly from a temperature and photoperiod point of view.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Van Leeuwen C, Friant P, Choné X, Tregoat, O, Koundouras S, Dubourdieu D. Influence of climate, soil, and cultivar on terroir. American Journal of Enology and Viticulture. 2004;55:207-217.
2. Barham E. Translating terroir: The global challenge of French AOC labeling. Journal of Rural Studies. 2003;19:127-138.
3. Deloire A, Vadour E, Carey V, Bonnardot V, Van Leeuwen C. Grapevine response to terroir: A global approach. Journal International des Sciences de la Vigne et du Vin. 2005;39:149-162.
4. Van Leeuwen C, Seguin G. The concept of terroir in viticulture. Journal Wine Research. 2006;17:1–10.
5. Kumšta M, Pavloušek P, Kupsa J. Influence of terroir on the concentration of selected stilbenes in wines of the cv. Riesling in the Czech Republic. Journal Horticultural Science. 2012;39:38-46.
6. Zsófi Z, Tótha E, Rusjanb D, Báloa B. Terroir aspects of grape quality in a cool climate wine region: Relationship between water deficit, vegetative growth and berry sugar concentration. Scientia Horticulturae. 2011;127:494–499.
7. Carey VA, Saayman D, Archer E, Barbeau G, Wallace M. Viticultural terroirs in Stellenbosch, South Africa. I. The identification of natural terroir units. Journal International des Sciences de la Vigne et du Vin. 2008;42:169-183.
8. Vaudour E. Les terroir viticoles. Définitions, caractérisation et protection. 2003. Dunod, Paris.
9. Scholz MBS. Tipologia dos cafés paranaenses: uma abordagem através da análise fatorial múltipla dos aspectos físico-químicos e sensoriais. Tese (Doutorado em Ciência de Alimentos) - Departamento de Ciência e Tecnologia de Alimentos, Universidade Estadual de Londrina, Londrina; 2008.
10. Guyot B, Gueule D, Manez JC, Perriot JJ, Giron J, Villain L. Influence de l´altitude et de l´ombrage sur la qualité des cafés arabica. Plantations, Recherche, Developpment. 1996;3:272-283.
11. Decazy F, Avelino J, Guyot B, Perriot JJ, Pineda C, Cilas C. Quality of different Honduran coffee in relation to several environments. Journal of Food Science. 2003;68:2356-2361.
12. Laviola BG, Martinez HEP, Salomão LCC, Cruz CD, Mendonça SM, Neto AP. Alocação de fotoassimilados em folhas e frutos de cafeeiro cultivado em duas altitudes. Pesquisa Agropecuária Brasileira. 2007;42:1521-1530.
13. Silva SA, Queiroz DM, Pinto FAC, Santos NT. Characterization and delimitation of the terroir coffee in plantations in the municipal district of Araponga, Minas Gerais, Brazil. Revista Ciência Agronômica. 2014;45:18-26.
14. Embrapa. Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ). Sistema brasileiro de classificação de solos. Brasília, Produção de Informação; 2006.
15. Embrapa. Manual de métodos de análise de solo. Rio de Janeiro: Ministério da Agricultura e do Abastecimento; 1997.
16. Jackson ML. Soil Chemical Analysis: Advanced Course. Madison: University of Wisconsin; 1969.
17. Zwick WR, Velicer WF. Factors influencing four rules for determining the number of components to retain. Psychol. B. 1986; 99:432-442.
18. Silva SA, Lima JSS. Multivariate analysis and geostatistics of the fertility of a humic Rhodic Hapludox under coffee cultivation. Revista Brasileira de Ciência do Solo. 2012;36:467-474.
19. Silva SA, Lima JSS, Souza GS, Oliveira RB, Silva AF. Variabilidade espacial do fósforo e das frações texturais de um Latossolo Vermelho Amarelo. Revista Ciência Agronômica. 2010;41:1-8.
20. Cambardella CA, Moorman B, Novak J, Parkin TB, Karlen DL, Turco RF, Knopk AE. Fiel-Scale Variability of soil properties in Central Iowa Soils. Soil Science Society American Journal. 1994;58:1501–1511.
21. Gonçalves ACA, Folegatti MV. Correlação especial entre retenção de água e textura do solo para fins de manejo de irrigação. Engenharia Agrícola. 2002;22:296-303.
22. Norton LD, Mamedov AI, Huang C, Levy GL. Soil aggregate stability as affected by long-term tillage and clay mineralogy. Advances in GeoEcology. 2006;38:422-429.
23. Darunsontaya T, Suddhiprakarn A, Kheoruenromne I, Prakongkep N, Gilkes RJ. The forms and availability to plants of soil potassium as related to mineralogy for upland Oxisols and Ultisols from Thailand. Geoderma. 2012;170:11-24.

24. Melo V F, Corrêa GF, Maschio PA, Ribeiro AN, Lima VC. Importância das espécies minerais no potássio total da fração argila de solos do triângulo mineiro. Revista Brasileira de Ciência do Solo. 2003; 27:807-819.
25. Melo VF, Singh B, Schaefer CEGR, Novais RF, Fontes MPFF. Chemical and mineralogical properties of kaolinite-rich Brazilian soils. Soil Science Society American Journal. 2001;65:1324-1333.
26. Silva SA. Terroir de café em lavouras do município de Araponga-MG. Tese (Doutorado em Engenharia Agrícola), Universidade Federal de Viçosa. 2012; 123.
27. Cressie N. Statistics for spatial data. New York: John Wiley; 1991.
28. Warrick AW, Nielsen DR. Spatial variability of soil physical properties in the field. In Applications of soil physics. (Ed D. Hillel) New York: Academic press. 1980;319-344.
29. Silva SA, Lima JSS, Oliveira RB, Souza GS, Silva MA. Análise espacial da erosão hídrica em um latossolo vermelho amarelo sob cultivo de café conilon. Revista Ciência Agronômica. 2007;38:335-342.
30. Bertoni J, Lombardi Neto F. Conservação do solo. São Paulo: Ícone. 4ª Ed. 1999;355.
31. Corrêa MM, Ker JC, Mendonça ES, Ruiz HA, Bastos RS. Atributos físicos, químicos e mineralógicos de solos da região das várzeas de Sousa (PB). Revista Brasileira de Ciência do Solo. 2003;27:311-324.
32. Souza Neto EL, Andrioli I, Beutler AN, Centurion JF. Atributos físicos do solo e produtividade de milho em resposta a culturas de pré-safra. Pesquisa Agropecuária Brasileira. 2008;43:255-260.
33. Lado M, Ben-Hur M. Soil mineralogy effects on seal formation, runoff and soil loss. Applied Clay Science. 2004;24:209-224.
34. Oliveira Junior JC, Souza LCP, Melo VF, Rocha HO. Variabilidade espacial de atributos mineralógicos de solos da formação Guabirotuba, Curitiba (PR). Revista Brasileira de Ciência do Solo. 2011;35:1481-1490.
35. Barbosa JN, Borem FM, Cirillo MA, Malta MR, Alvarenga AA, Alves HMR. Coffee Quality and Its Interactions with Environmental Factors in Minas Gerais, Brazil. Journal of Agricultural Science. 2012;4:181-190.
36. Nascimento MN, Alves JD, Soares AM, Castro EM, Magalhães MM, Alvarenga AA, Silva GH. Alterações bioquímicas de plantas e morfológicas de gemas de cafeeiro associadas a eventos do florescimento em resposta a elementos meteorológicos. Ciência Rural. 2008; 38:1300-1307.

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