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EVALUATION OF THE CHEMICAL ATTRIBUTES OF THE SOIL IN COFFEE CULTIVATING AREAS

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Abstract: Coffee is one of the most important agricultural products in Brazil due to its economic return. This advance is associated with appropriate soil management practices and initiatives arising from public policies that encourage the strengthening of coffee production. However, the lack of scientific knowledge about the chemical attributes of the soil and its relationship with the natural vegetation constitutes an obstacle to the conservation and management of these areas, as well as to interventions for the rehabilitation of degraded areas. Thus, this work aimed to evaluate the chemical attributes of soils under coffee cultivars of the Robusta variant species that were planted at the Instituto Federal de Rondônia *Campus* Cacoal and at two rural properties in the same municipality. The methods used to carry out this study consisted of collecting soil samples, observing the levels of Organic Matter (OM), P, K, Na, Al, Ca, Mg, ($H^{+}+Al^{3+}$), Fe, Cu, Zn, Mn, pH, Base Saturation (V%), Aluminum Saturation (m%) and effective CTC. The study was completely randomized and the data underwent statistical analysis using the independent t-test and one-way ANOVA. Pearson's bivariate correlation was also analyzed. Soils at a depth of 0 to 20 cm that had a high M.O. showed lower pH value in $CaCl_2$. Only the soil of Producer 2 at a depth of 0 to 20 cm, among the soils under coffee cultivation, needed to have its acidity corrected. None of the evaluated soils required zinc fertilization. Furthermore, there is a negative and strong correlation between Ca and (m%); as well as a very strong and positive correlation between the M.O. and the Mg.
Keywords: Soil. Chemical attributes. Rondônia.

INTRODUCTION

Coffee is one of the most important agricultural products in Brazil due to the return economic (SAATH et al., 2015). At the regional level, the State of Rondônia is the largest coffee producer, with its production area exceeding 93% compared to the State of Amazonas, the second largest producer in the northern region. In view of its socioeconomic importance, coffee growing in Rondônia provides work and income generation that subsidize a large part of family farming.

Rondônia is also the 2nd largest producer of the species *Coffea canephora,* popularly known as "canéfora" coffee, according to the National Supply Company (CONAB, 2021). More than 90% of the coffee area is planted with canephora coffee, establishing itself as the species that sustains the state's economy. However, there was a decrease of 7.4% compared to the 2020 season (CONAB, 2021), which may be associated with soil chemical attributes. Despite the opening of new production areas, which were renovated with equipment of high technological potential, production fertilization and soil maintenance carried out by producers in Rondônia are still far from ideal (MARCOLAN et al., 2015).

The lack of scientific knowledge about soil fertility and its relationship with natural vegetation constitutes an obstacle to the conservation and management of these areas, as well as to interventions for the rehabilitation of degraded areas (ALMEIDA et al., 2005). The evaluation of soil chemical attributes is the first step towards defining the necessary measures to correct and manage its fertility. Among the advantages of this evaluation, the following stand out: the low operating cost of the analyses, availability of laboratories, speed in obtaining and delivering the results and the possibility of planning the recommendation of doses of fertilizers and correctives that must be applied before the implantation of the culture (SILVA et al., 1998).

In view of this, the present study aimed to evaluate the chemical attributes of the soil under coffee plantations. For this, the content of macro and micronutrients, aluminum, organic matter, pH in water and calcium chloride and potential acidity were analyzed. The results presented may serve as a basis for future management or restoration plans in this environment, as this is a group of species of recognized economic importance in the State of Rondônia

MATERIAL AND METHODS

SAMPLE COLLECTION

The samples were collected in the rural region of the municipality of Cacoal, located in the interior of the State of Rondônia. It was adopted as a criterion for the selection of study areas, soils that were under coffee cultivation and during the harvest period. In total, samples were collected from three different areas, two belonging to producers who cultivate coffee for commercial activity, identified as PROD1 and PROD2; and one belonging to the *campus* of the Federal Institute of Rondônia, identified as IFRO, intended for studies and own consumption.

For each region, samples composed of soils were obtained in two depth intervals: from 0 to 20 centimeters and from 20 to 40 centimeters. With the purpose of comparing the results between the soils under cultivation area and the soil considered "virgin" for coffee production, a sampling was also carried out in the remaining forest zone, considered as a Native Forest Zone and, therefore, identified like KILLS.

The abbreviations that represent each sample according to the collection area and depth, in addition to the geographic coordinates of the collection points are shown in Table 1.

Composite sampling was carried out based on the methodology described by Dick and his collaborators (1996). For this, an auger was used to collect the samples, which were subsequently subjected to the drying process in the shade, crushed, homogenized and sieved through a mesh with an opening of 2 mm (Dick et al., 1996). Afterwards, each sample could be denominated as "Fine Air Dry Earth" (TFSA), the way in which they were used in the determinations. The design was completely randomized with three plots (replications) in each soil (plot).

CHEMICAL ANALYSIS OF SOILS

All the tests for obtaining the chemical attributes of the soils were carried out at the Soil Laboratory of the Federal Institute of Rondônia -*Campus* Cacoal, based on the Soil Chemical Analysis Manual for the experimental procedures (EMBRAPA, 1997). In general, the analyzes carried out were the content of macro and micronutrients, aluminum, organic matter, pH in water and in calcium chloride and potential acidity.

Analysis of calcium ion concentrations (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{2+}), copper (Cu^{2+}), zinc (Zn^{2+}) and manganese (Mn^{2+}) was performed by means of atomic absorption spectrophotometry with air-acetylene flame. For the analyzes of Ca^{2+} e Mg^{2+}, commercial standard solutions were used, with a concentration of 1000 mg L^{-1}. For micronutrient analysis, a multielement standard was used, with a concentration of 100 mg $L^{-1.}$

For the quantification of sodium (Na) and potassium (K) a flame photometer was used; the phosphorus (P) content was obtained by spectrophotometry in the UV-VIS region at a wavelength of 660 nm.

For the determination of exchangeable aluminum and potential acidity, the method of neutralization volumetry was followed with a standard solution of sodium hydroxide (NaOH) 0.025 mol L-1.

Soil pH analysis was carried out in water and also in a solution of calcium chloride (CaCl2) 0.01 mol L^{-1}. Finally, the organic matter content (O.M.) was obtained by back titration method, using 0.05 mol L^{-1} ferrous ammonia sulfate as titrant.

With the data obtained in this research, the calculation of the Sum of Bases (S), Cation

Description	Depth (cm)	Acronyms	Coordinates Geographical
Soil collected under Zona de Mata	0-20	MATA-20	11° 28’ 35,81” S
	20-40	MATA- 40	61° 22’ 44,46” O
Soil collected in the IFRO area	0-20	IFRO-20	11° 28’ 37,89” S
	20-40	IFRO-40	61° 22’ 45,08” O
Soil collected in the cultivation area from Producer 1	0-20	PROD1-20	11º 22’ 9,628” S
	20-40	PROD1-40	61º 19’ 50,584” O
Soil collected in the cultivation area from Producer 2	0-20	PROD2-20	11º 29’ 37,572” S
	20-40	PROD2-40	61º 26’ 25,152” O

Table 1- Acronyms representing the samples according to the description and depth of collection, and geographic coordinates of the collection points.

	MATA	IFRO	PROD1	PROD2	MATA	IFRO	PROD1	PROD2
Analysis	Depth 0 - 20 cm				Depth 20 - 40 cm			
Ca	2,6395a	5,1689b	4,1886b	2,5908a	1,8794c	3,5380d	4,1700d	1,6292c
($cmol_c\ dm^{-3}$)					0,2090c	0,3325d	0,8165d	0,8582d
Mg	0,4323a	0,4612a	0,8760b	1,2178b				
Fe	49,0025a	53,2250b	32,6067b	51,6183b	25,0908c	51,4217d	29,7233d	50,9333d
Cu	3,0242a	1,8855b	2,5867b	0,2417b	3,6500c	1,6317d	2,7638d	0,2917d
($mg\ dm^{-3}$)					9,3707c	4,3207d	5,7875d	1,2762d
Zn	10,5367a	11,4573b	5,4225b	1,3297b	107,0833c	156,7500d	50,3500d	6,8533d
Mn	252,7333a	322,8667b	46,1333b	10,8483b				

* Values marked with the same letter do not differ in relation to soil in Zona de Mata by the Tukey HSD post-hoc test at 5% probability. Letters a and b were used to compare means at a depth of 0 to 20 cm and letters c and d, at a depth of 20 to 40 cm.

Table 2- Ca and Mg contents in cmolc dm^{-3} and Fe, Cu, Zn and Mn contents in mg dm^{-3}.

	MATA	IFRO	PROD1	PROD2	MATA	IFRO	PROD1	PROD2
Analysis	Depth 0 - 20 cm				Depth 20 - 40 cm			
Na	2,0a	4,0b	4,0b	3,3a	1,0c	1,0c	5,0d	3,7d
$mg\ dm^{-3}$					10,0c	20,0d	79,9d	39,9d
K	33,3a	79,9b	79,9b	39,9a				
$H^+ + Al^{3+}$	3,34a	3,69a	3,43a	5,03b	3,36c	3,12c	3,09c	5,79d
$cmol_c\ dm^{-3}$					0,24c	0,03d	0,00d	0,24c
Al^{3+}	0,04a	0,04a	0,00b	0,10b				
pH (H_2O)	6,21a	6,11a	6,02a	5,95a	5,57c	5,86c	6,04d	5,76c
pH ($CaCl_2$) 5,27a	5,51a	5,31a	5,13a		4,27c	5,12d	5,32d	4,75d

* Values marked with the same letter do not differ in relation to soil in Zona de Mata by the Tukey HSD post-hoc test at 5% probability. Letters a and b were used to compare means at a depth of 0 to 20 cm and letters c and d, at a depth of 20 to 40 cm.

Table 3- Sodium and potassium contents in mg dm^{-3}, potential acidity contents (H^++Al^{3+}) of aluminum (Al^{3+}) in $cmol_c\ dm^{-3}$ and pH in water and $CaCl_2$.

Exchange Capacity (CTC), Base Saturation (V%) and Aluminum Saturation (m%) was performed in order to obtain results that could help in the possible fertilization and liming of the soil.

In addition, data were tested for normality and homogeneity, with analysis of variance performed using one-way ANOVA and means compared using the Tukey test at 5% probability.

For the purposes of data treatment, soil under coffee cultivation at a depth of 0 to 20 cm was compared with soil in a forest zone at the same depth. This same comparative procedure was performed for soils at a depth of 20 to 40 cm.

Some soil parameters were compared by the independent t-test relating the depth ranges from 0 to 20 and 20 to 40 cm. Pearson's bivariate correlation was also performed. For the statistical treatment of the data, the RStudio application was used.

RESULTS AND DISCUSSION

ANALYTICAL PHASE OF OBTAINING THE RESULTS

The values determined in the analyzes of the concentrations of calcium ions (Ca^{2+}), magnesium (Mg^{2+}), ferro (Fe^{2+}), copper (Cu^{2+}), zinc (Zn^{2+}) and manganese (Mn^{2+}) are shown in table 2.

As it is possible to observe in table 2, only the calcium concentrations in the soil of the second producer, at both depths (PROD2-20 and PROD2-40), and the concentration of magnesium in the IFRO soil at a depth of 0-20cm (IFRO-20). In addition, all soils had different concentrations of micronutrients compared to the soil in Zona de Mata, which was already expected, since, as this is a coffee production soil, interventions have already been carried out, such as liming and fertilization, by example.

Table 3 shows the results of sodium (Na) and potassium (K) contents; exchangeable aluminum and potential acidity; pH both in water and in calcium chloride solution.

As for the sodium and potassium content, as shown in Table 3, the PROD-20 soil again showed similar values compared to the soil in Zona de Mata.

Still according to table 3, it is emphasized that pH values in water and in calcium chloride, at a depth of 0 to 20 cm, are very close to each other. Each soil also has a pH in CaCl2 lower than the pH in water, which was predictable given that the addition of calcium chloride influences the ionic strength of the solution. A similar result was found by (SOUZA et al., 2013) when studying the pH in incubated dystrophic red yellow clay soil.

In general, pH values in water are greater than 5.5 and less than 7, which are considered adequate for nutrient absorption. According to Malavolta and his collaborators (1997), the pH range between 6 and 7 is considered ideal, since there is a low availability of aluminum, keeping all other nutrients with good availability (MALAVOLTA et al., 1997).

One-way ANOVA showed no difference in pH measurements between soils at a depth of 0 to 20 cm ($p = 0.186$). Soil acidity is an important parameter in the use of nutrients by plants, but pH alone must not be taken into account. The determination of potential acidity and aluminum are necessary to obtain a more accurate reading of the analyses. In relation to soils at a depth of 20 to 40 cm, there was a significant difference in pH values ($p = 0.0116$) only between MATA-40 and PROD1-40 soils.

Aluminum saturation was what probably contributed to the decrease in pH as depth increased, as MATA-40 and PROD2-40 soils had higher aluminum content in their composition. The one-way ANOVA showed that there is a difference in the mean aluminum contents between the soils at a depth of 20 to 40 cm ($p < 0.01$). The post-hoc Tukey HSD showed that there is no difference in aluminum content between MATA-40 and PROD2-40 soils. The percentage of saturation tolerated by the coffee crop is approximately 25% (NETO et al., 2001).

Although all determinations have content below the critical value, it is desirable that the aluminum saturation always tends to zero. A high aluminum content associated with a low pH represents a risk for the coffee crop, as they can favor toxic elements and affect nutrient availability. As the pH decreases, it favors the availability of aluminum, since, in addition to Al3+ being absorbed by the plant, it prevents the exchangeable ions of Ca2+, Mg2+ and K+ from occupying the exchange complex, causing the leaching of these nutrients in a later period. fertilization (MARCOLAN et al., 2009).

Studies carried out in the soils of the Amazon region point out that the canephora coffee tree has a lower tolerance to Al^{3+} than the arabica coffee tree, especially when this toxic species is concentrated in the subsurface parts of the soil. Thus, the quantification of Al^{3+} in soils under coffee cultures of the *Coffea canephora* species is essential to monitor the development of the plantation (MAURI et al., 2004; MATIELLO et al., 2008; GUARÇONI et al., 2009).

The values of the sum of bases (S), cation exchange capacity (CEC), base saturation (V%) and aluminum saturation (m%) at two depths are shown in table 4.

The reference value for the base saturation content (V%) is 60% for the calculation of liming in coffee crops in the state of Rondônia, as evidenced by Marcolan et al. (2009) in research on nutritional management of soil in the state. Based on this, it can be seen in table 4 that only the soils in PROD2 and in Zona de Mata were below the recommended level. This evidence can be justified by the fact that the soil of the Amazon region presents low base saturation, mainly in relation to the magnesium content. It is also possible to notice that in the soil where the aluminum saturation (m%) was higher, there was a lower base saturation content, whose phenomenon was also discussed by Marcolan et al. (2015).

The phosphorus (P) and Organic Matter (M.O.) contents in the analyzed soils can be consulted in table 5.

Table 5 shows that the phosphorus content is mostly concentrated on the soil surface (0 to 20 cm), with the exception of the PROD1 soil, since the concentration of this macronutrient increases with depth. It is important to emphasize that the PROD2 soil has a lower concentration of phosphorus, indicating the need for replacement, since it is a coffee production soil.

It is also observed that there is a lower concentration of organic matter (O.M.) as the depth increases. This is because it is the result of the deposition of decomposing waste over time and, therefore, the organic matter tends to remain more concentrated on the surface (NETO et al., 2001).

At this point, it is also essential to show that organic matter is another factor that influences soil acidity and, therefore, the measurement of soil pH in a solution of $CaCl_2$ 0,01 mol L^{-1} becomes necessary because it takes into account the mineralization of organic matter during the incubation period. In this way, the addition of salt allows correcting errors of overestimation of the need for liming. In addition, organic matter is a source of weak acids and, in this way, calcium chloride enables the "extraction" of the H+ ion into the solution, which can be detected by the pHmeter electrode (SOUZA et al., 2013).

Figure 1 represents the scatterplot between organic matter and pH in CaCl2.

Through Pearson's analysis, it was found that there is a negative and moderate correlation between O.M. and the pH in $CaCl_2$ at a depth of 0 to 20 cm ($r = -0.54$; $p > 0.05$). Even having a "p" value with hypothesis of null linear

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Analysis		MATA	IFRO	PROD1	PROD2	MATA	IFRO	PROD1	PROD2
		Depth 0 - 20 cm				Depth 20 - 40 cm			
S		3,17a	5,85b	5,29b	3,93b	2,12c	3,93d	5,21d	2,61d
	$cmol_c\ dm^{-3}$					5,48c	7,04d	8,30d	8,39d
CTC		6,51a	9,54b	8,72b	8,95b				
V		48,64a	61,33b	60,62b	43,85b	38,68c	55,73d	62,77d	31,05d
	%					10,32c	0,75d	0,00d	8,45d
m		1,13a	0,62a	0,00b	2,38b				

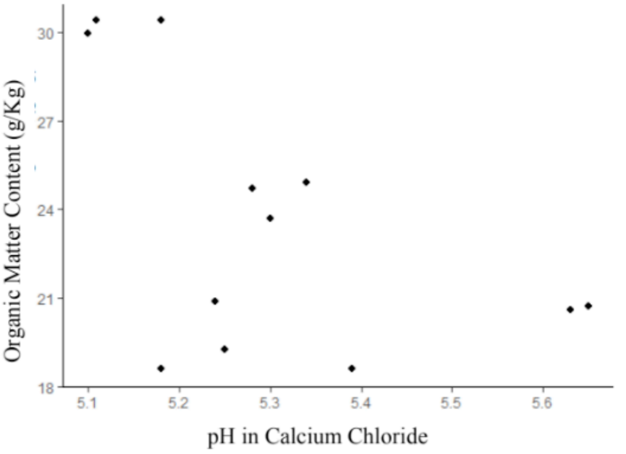
* Values marked with the same letter do not differ in relation to soil in Zona de Mata by the Tukey HSD post-hoc test at 5% probability. Letters a and b were used to compare means at a depth of 0 to 20 cm and letters c and d, at a depth of 20 to 40 cm.

Tabela 4- Base sum values (S), cation exchange capacity (CEC), base saturation (V%) and aluminum saturation (m%) at two depths.

Analysis		MATA	IFRO	PROD1	PROD2	MATA	IFRO	PROD1	PROD2
			Depth	0-20 cm		Depth 20-40 cm			
P	$mg\ dm^{-3}$	9,43a	26,66b	35,20b	6,57b	7,03c	2,53d	38,39d	5,43c
M.O.	$g\ Kg^{-1}$	18,81a	20,74b	24,44b	30,26b	8,54c	10,71d	22,38d	28,01d

* Values marked with the same letter do not differ in relation to soil in Zona de Mata by the Tukey HSD post-hoc test at 5% probability. Letters a and b were used to compare means at a depth of 0 to 20 cm and letters c and d, at a depth of 20 to 40 cm.

Tabela 5- Phosphorus (P) concentration values in $mg\ dm^{-3}$ and organic matter in $g\ Kg^{-1}$.



* The points on the plot represent independent values. As the analyzes were carried out in triplicate, there are a total of 12 (twelve) points since they are 4 regions in the depth of 0 to 20 centimeters.

Figure 1- Scatter plot between the M.O. in $g\ Kg^{-1}$ and the pH in $CaCl_2$.

relationship, it is possible to see in figure 1 that the soils with higher OM. have lower pH value in $CaCl_2$.

LIMING

Liming is the main measure for soil acidity correction. The liming recommendation criteria are variable according to the analytical principles, proposed objectives, choice of index (base saturation, exchangeable aluminum content and pH), as well as the culture to be implanted (SCHLINDWEIN et al., 2014).

The Base Saturation (V%) method allows calculating the liming requirement (NC) in order to stipulate the amount of limestone in t ha-1 that must be applied to the coffee crop. It is important to point out that the state's soil has a low magnesium content and, therefore, it is recommended to apply dolomitic limestone. In view of the above, a prior consultation was carried out on the product packaging to calculate the need for liming. The PRNT of 86% was used and the target base saturation was 60% (MARCOLAN et al., 2009).

The results of the liming requirement (NC) calculation at a depth of 0 to 20 cm are shown in table 6.

As the soils under coffee plantations are already production areas, it is recommended the surface application of limestone without digging holes, therefore, data from 0 to 20 cm deep were used to calculate the need for liming(MARCOLAN et al., 2009).

It is observed, in table 6, that only the PROD2-20 soil needed to be corrected, applying about 1.68 t ha^{-1}. It is also noted that the MATA-20 soil required 0.86 t ha^{-1} of limestone, however, as it is a forest area, the recommended liming for coffee production was not followed.

Figure 2 shows the reaction dynamics that probably occur in the soil after limestone application.

As can be seen in the equation in Figure 2, calcium carbonate, a basic salt, provides hydroxyl for ion neutralization (H^+). The hydrolysis of carbonate ions (CO_3^{2-}) and bicarbonate (HCO_3^-) provides hydroxyl ions (OH^-) that react with the ion (H^+), forming water. The Ca^{2+} binds to the surface of the colloid and the CO_2, being a gas, it tends to escape into the atmosphere. A similar analysis was performed by Primavesi et al. (2004) when studying the characteristics of agricultural correctives.

CHEMICAL ATTRIBUTES AND FERTILIZATION

The levels of organic matter, phosphorus and potassium provide subsidies for recommending soil fertilization.

Typically, soil NPK levels (nitrogen, phosphorus and potassium) are measured for fertilizer recommendations. However, no nitrogen results were obtained by leaf analysis and, in this case, the organic matter content was used for nitrogen fertilization.

The recommendation for production fertilization was made based on soil analysis and on the basis of expected productivity (MARCOLAN et al., 2009), as shown in figure 3.

In relation to micronutrients, concentrations of Zn, Fe, Cu and Mn were obtained in this research. The recommendation for fertilization for production of robusta coffee was based on soil analysis and expected productivity. According to the results, fertilizer recommendations can be made in order to nourish the coffee tree. The calculations were made using the Excel application and are shown in Table 7.

Table 7 shows that there is a greater demand for organic matter when the depth increases, except for the PROD1 and PROD2 soils, where the concentrations showed little variation, as shown in Figure 4.

The relationship between the M.O. and the depth was expected, as the organic matter is concentrated in the surface layer of the soil.

		MATA		IFRO	PROD1	PROD2
S	$cmol_c\ dm^{-3}$		3,17a	5,85b	5,29b	3,93b
CTC			6,51a	9,54b	8,72b	8,95b
V	%		48,64a	61,33b	60,62b	43,85b
NC	$t\ ha^{-1}$		0,86	---	---	1,68

* Values marked with the same letter do not differ in relation to soil in Zona de Mata by the Tukey HSD post-hoc test at 5% probability. Letters a and b were used to compare means at depths from 0 to 20 cm.

Table 6- Results of the liming requirement (NC) calculation at a depth of 0 to 20 cm.

$$CaCO_3(s) \xrightarrow{H_2O} Ca^{2+}(aq) + CO_3^{2-}(aq)$$

$$CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^{-}(aq) + OH^{-}(aq) \qquad Kb = 2,2x10^{-4}$$

$$HCO_3^{-}(aq) + H_2O(l) \rightleftharpoons OH^{-}(aq) + H_2O(l) + CO_2(g) \qquad Kb = 2,4x10^{-8}$$

Figure 2 - Chemical reaction in the soil after application of limestone

	Productivity $sc\ ha^{-1}$	$g\ Kg^{-1}$	Reference
M.O.	60-70	270	<20 $g\ Kg^{-1}$
		180	20 $g\ Kg^{-1}$ a 30 $g\ Kg^{-1}$
		135	>30 $g\ Kg^{-1}$
	>70	300	<20 $g\ Kg^{-1}$
		200	20 $g\ Kg^{-1}$ a 30 $g\ Kg^{-1}$
		150	>30 $g\ Kg^{-1}$
P	60-70	80	<10 $mg\ dm^{-3}$
		60	10 $mg\ dm^{-3}$ a 20 $mg\ dm^{-3}$
		40	>20 $mg\ dm^{-3}$
	>70	90	<10 $mg\ dm^{-3}$
		70	10 $mg\ dm^{-3}$ a 20 $mg\ dm^{-3}$
		50	>20 $mg\ dm^{-3}$
K	60-70	240	<1,5 $mmol_c\ dm^{-3}$
		160	1,5 $mmol_c\ dm^{-3}$ a 3,0 $mmol_c\ dm^{-3}$
		80	>3,0 $mmol_c\ dm^{-3}$
	>70	270	<1,5 $mmol_c\ dm^{-3}$
		180	1,5 $mmol_c\ dm^{-3}$ a 3,0 $mmol_c\ dm^{-3}$
		90	>3,0 $mmol_c\ dm^{-3}$
Zn	---	2	<0,5 $mg\ dm^{-3}$
		1	0,5 $mg\ dm^{-3}$ a 1,2 $mg\ dm^{-3}$
		0	>1,2 $mg\ dm^{-3}$

Figure 3 - Recommendation for production fertilization to be carried out in the soil under coffee planting.

Source: Adapted from Marcolan et al., 2009

According to table 7, the PROD2 soil required 90 kg ha^{-1} de P_2O_5 and 270 Kg ha^{-1} of K_2O, indicating that these nutrients were below the recommended for the desired productivity. It was also possible to observe that the PROD1 and PROD2 soils presented very close required amounts of nutrients at both depths. The t-test for two independent samples showed no effect of depth on zinc content in PROD1 soils (p=0.35); as well as, the same result was obtained in the PROD2 soils (p=0.73). It is inferred, in this case, that the soils have a balanced Zn mobility, thus providing a uniform absorption by the roots. It was not necessary to add zinc to the soil of any producer, since the amount present, until the time of collection, supplied the demand for this micronutrient.

The concentrations of copper, iron and manganese in the soil served to help the agronomist and the producer in the visual diagnosis of the nutritional state of the plant, because with the data of the chemical attributes of the soil it is possible to make allusions with aspects of color, size and shape of the plant. leaf, which is the organ that best reflects the nutritional status of the plant (FAQUIN, 2002).

CORRELATION BETWEEN VARIABLES

A bivariate linear correlation matrix was created between all the parameters analyzed in this research, as shown in figure 5.

It can be seen in figure 5 that there is a negative and strong correlation between Calcium and Aluminum Saturation, to be analyzed by circle size and color intensity. Pearson's correlation can confirm this observation between Ca and (m%) ($r = -0.79$; $p<0.001$). In this case, there is a correlation statistically different from zero and this inversely proportional relationship can be seen in figure 6.

It is possible to verify in figure 6 that calcium is concentrated in soils with low aluminum saturation. This result corroborates, therefore, with the hypothesis that the leaching of Ca^{2+} is caused by Al^{3+} (MARCOLAN et al., 2009).

It is also possible to notice that there is a very strong and positive correlation between the M.O. and Mg ($r=0.92$, $p<0.01$). The scatter plot in figure 7 shows a directly proportional relationship between these two variables.

According to figure 7, the scatter plot between the magnesium content and the organic matter content, it is possible to notice that the coefficient is 0.84, indicating that these two variables are very close to a regression, thus being able to deduce that there is a relative "dependency" between the two factors.

FINAL CONSIDERATIONS

Only soil PROD2-20, among the soils under coffee cultivation, needed to have the acidity corrected, applying about 1.68 t ha^{-1}. None of the evaluated soils needed zinc fertilization, as the amount present, until the time of collection, supplied the demand for this micronutrient.

It was also observed that, in the evaluated soils, there is a negative and strong correlation between Calcium and Aluminum Saturation and a very strong and positive correlation between OM. and the Mg.

As a practical contribution, this research made it possible to present the recommendations for fertilization and liming to producers in the region through a technical report in order to guide them regarding interventions in the soil according to the desired productivity.

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		IFRO		PROD1		PROD2	
Depth		0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
MO	Kg ha^{-1}	180	270	200	200	150	200
P	P_2O_5 (Kg ha^{-1})	40	80	50	50	90	90
K	K_2O (Kg ha^{-1})	160	240	180	180	270	270
Zn	$ZnSO_4$ (Kg ha^{-1})	0	0	0	0	0	0

Table 7- Amounts of organic matter, phosphorus and potassium recommended for fertilization of coffee crops at two depths.

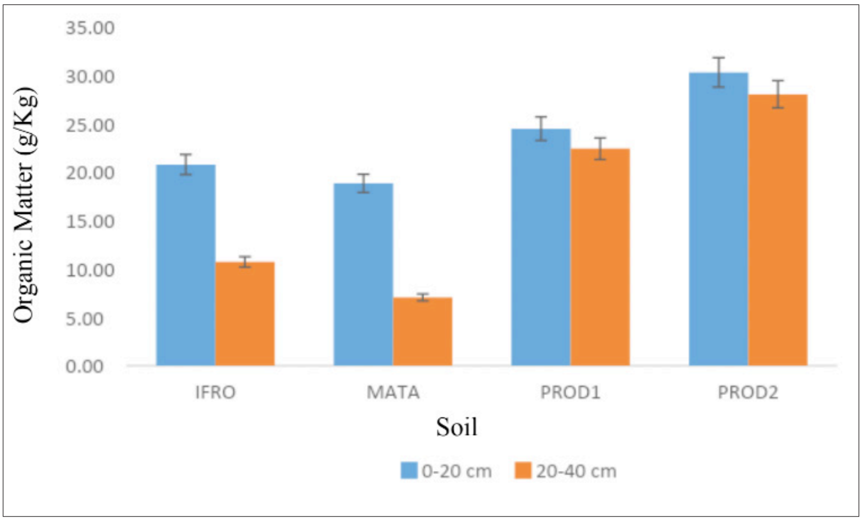


Figure 4- Soil organic matter content at two depths.

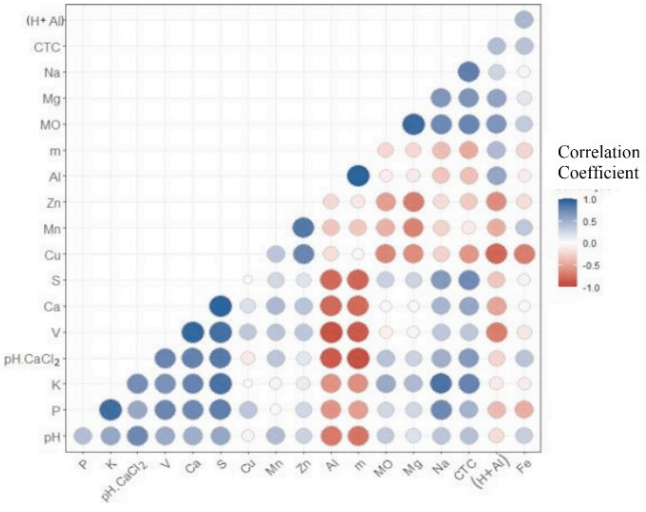
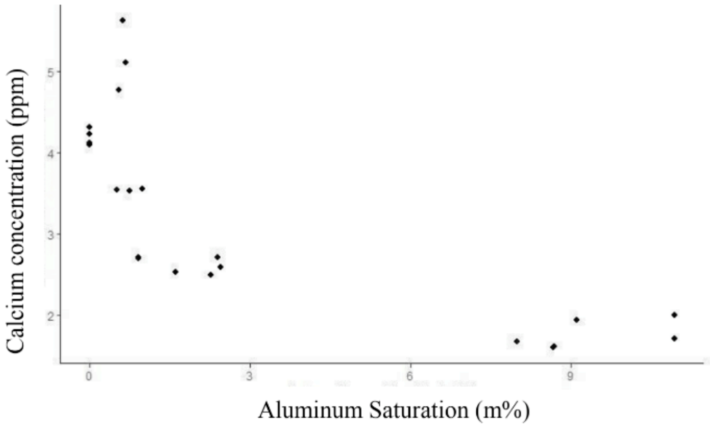
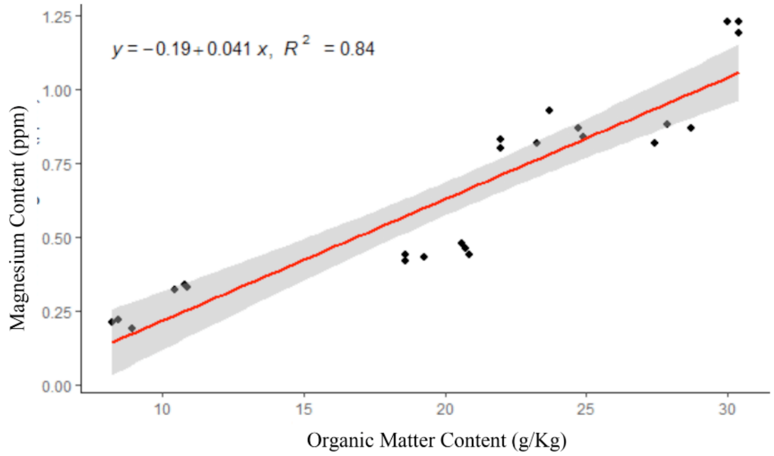


Figure 5- Pearson linear correlation matrix.



* The points on the plot represent independent values. As the analyzes were carried out in triplicate, there are a total of 24 (twenty-four) points since they are 4 regions in the depth of 0 to 20 and 20 to 40 cm. In this graph, some points are overlapping.

Figure 6- Scatter plot between calcium concentration and aluminum saturation.



* The points on the plot represent independent values. As the analyzes were carried out in triplicate, there are a total of 24 (twenty-four) points since they are 4 regions in the depth of 0 to 20 and 20 to 40 centimeters.

Figure 7- Scatter plot between magnesium concentration in ppm and organic matter content in g Kg^{-1}.

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