CHEMICAL ATTRIBUTES OF AREAS UNDER DIFFERENT CULTIVATION SYSTEMS IN CHAPADA DO ARARIPE

ATRIBUTOS QUÍMICOS DE ÁREAS SOB DIFERENTES SISTEMAS DE CULTIVO NA CHAPADA DO ARARIPE

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ABSTRACT

The introduction of crops in the Chapadas, including the Chapada do Araripe in northeastern Brazil, allows the development of essential productive areas, especially in areas of the semiarid region of the Caatinga. However, the management of these agricultural areas without subsequent recovery may lead to degradation of the soil and environment as measured by assessing the chemical soil attributes. The purpose of the present work was to evaluate and map the chemical attributes of oxisol under different cultivation systems in Chapada do Araripe. The experiment was carried out in the municipality of Moreilândia, state of Pernambuco. Thus, we evaluated areas with native vegetation, areas with secondary vegetation, and 35 areas with different crops, including cassava, pigeon pea, and pasture. In each area, 70 soil samples were collected at depths of 0–0.20 and 0.20–0.40 m in sections of approximately 10 hectares. The pH, water, organic matter, available nutrients (P, K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}) and acidity were analyzed. The results were subjected to descriptive, geostatistical, and univariate analyses. The studied areas in Chapada do Araripe presented alterations in the chemical indicators of soil quality under different uses by anthropic action.

KEY WORDS: Soil degradation. Soil use. Spatial variability.

RESUMO

A introdução de lavouras nas Chapadas, incluindo a Chapada do Araripe no Nordeste do Brasil, permite o desenvolvimento de áreas produtivas essenciais, especialmente em áreas do semiárido da Caatinga. No entanto, o manejo dessas áreas agrícolas sem posterior recuperação pode levar à degradação do solo e do meio ambiente, medida pela avaliação dos atributos químicos do solo. O objetivo do presente trabalho foi avaliar e mapear os atributos químicos de latossolos sob diferentes sistemas de cultivo na Chapada do Araripe. O experimento foi realizado no município de Moreilândia, estado de Pernambuco. Assim, avaliamos áreas com vegetação nativa, áreas com vegetação secundária e 35 áreas com diferentes culturas, incluindo mandioca, feijão caupi e pasto. Em cada área, 70 amostras de solo foram coletadas em profundidades de 0–0,20 e 0,20–0,40 m em seções de aproximadamente 10 hectares. Foram analisados pH, água, matéria orgânica, nutrientes disponíveis (P, K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}) e acidez. Os resultados foram submetidos a análises descritivas, geoestatísticas e univariadas. As áreas estudadas na Chapada do Araripe apresentaram alterações nos indicadores químicos de qualidade do solo sob diferentes usos por ação antrópica.

PALAVRAS-CHAVE: Degradação do solo. Uso do solo. Variabilidade especial.

INTRODUCTION

The Chapada do Araripe is one of the main reliefs of the Brazilian Northeast Region. In addition to its indirect importance as a source of food and water for different cities in the Brazilian semiarid region. It is located in the semiarid area of the Caatinga with elevations of approximately 1000 m at the highest points and greater precipitation and lower temperatures relative to the surrounding Caatinga[1]. The predominant soil in Chapada do Araripe is medium-texture latosol (oxisol) from sandstone due to the erosion of a series of sediments[2].

The Chapadas are important for agriculture and the establishment of pastures to feed cattle, owing to the flat relief and deep soil; however, the fundamental limitations are the low capacity to develop sufficient electrical charges for base retention, high phosphorus complexation, and high levels of toxic aluminum. However, when formed at altitudes, such as the case of Chapada do Araripe, the surface layers have a higher content of organic matter, which is essential for the maintenance of the soil and biological cycle in the environment[3].

The changes caused by soil cultivation and livestock, lack of monitoring and management, and low natural soil fertility can be analyzed through chemical, physical, and biological variables and statistical techniques. Among these variables, the chemical attributes of the soil are the most commonly used, coupled with conventional, multivariate, and geostatistical techniques, which identify variations that occur in a given location or region, in order to promote sustainable agriculture. The knowledge of the spatial variability of the chemical attributes of soils is indispensable to reduce impacts of inadequates practices and soil degradation[4]. In addition, multivariate statistical analysis, linked to other techniques, has been widely used, given that it can clarify the maximum interactions and demonstrate the most variables[5].

The Chapada do Araripe has several cultivation and management systems that may be altering the quality or availability (nutrients) of soil attributes. Still, despite the advances in agriculture and livestock in Chapada do Araripe, there are not yet studies that evaluate chemical attributes and which crops are less harmful to the soil in the region. Evaluating these attributes through different analyses could help identify current conditions and thus indicate the best cultivation system that allows increased productivity and soil protection in this specific region. Therefore, this study aimed to evaluate the chemical attributes of oxisol in different cultivation and livestock systems in Chapada do Araripe in the municipality of Moreilândia-PE.

MATERIALS AND METHODS

The municipality of Moreilândia belongs to the Sertão Pernambucano region, which includes the Chapada do Araripe, located at 07°37′51″S, 39°33′04″W. The climate of the region is characterized according to the classification of Köppen as Bshw', steppe, semiarid hot, with the rainy season delayed for the autumn.

The areas used in this study are located in the communities of Beira da Serra, Mosquito, Serra do Alegre, Munduri, Cochos, Mandacaru, and Guedes, which are located in Chapada do Araripe, representing a total area of 9.441 ha with an average altitude of 940 m.

The soil samples for this study were collected in July and August 2019 to determine soil nutrient levels in 35 areas before planting in different types of land use. The areas were each approximately 10 hectares, subdivided into 8, 7, 7, 5, and 8 areas with respective crops: cassava (*Manihot esculenta* Crantz), pigeon pea (*Cajanus cajan* (L.), pasture (grasses *Brachiaria*), uncultivated, native vegetation, and secondary vegetation (consisting of herbaceous and shrub-tree plants). Regardless of the use, the areas were not previously subjected to the correction of soil acidity, and only the areas cultivated with cassava received fertilization by incorporating livestock manure (2.000 kg ha^{-1}).

A total of 1750 simple samples were collected from depths of 0–0.20 m and 0.20–0.40 m to obtain 70 composite samples, for the 35 areas, georeferenced with a GPS (Garmin GPSMap 76CSx) with the UTM coordinate system (Universal Transversa de Mercator). The samples were stored in plastic bags and sent to the Laboratory of Soil and Plant Analysis of the Federal Institute of Sertão Pernambucano-*Campus* Petrolina Zona Rural, where they were analyzed for pH, soil organic matter (SOM), phosphorus (P), potassium (K^+), sodium (N^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), aluminum (Al^{3+}), and potential acidity (H + Al), according to the procedures recommended[6]. The sum of bases (BS), cation exchange capacity (CEC), and percentage of base saturation (V%) were calculated.

The data were subjected to an analysis of variance (ANOVA) by soil depth after verifying the normality of the residues using the Shapiro-Wilk test. When significant differences were detected, the means were separated using Duncan's test ($p < 0.05$). The analyses were performed using R version 4.0.2 (Cran, 2020). The classification of the coefficient of variation (CV) followed the methodology[7] as follows: less than 12% (low), between 12 and 60% (average), and above 60% (high).

Using the GS$^+$ program, semivariograms were obtained and adjusted to the spherical, exponential, and Gaussian models. The kriging technique was used to predict non-sampled areas and obtain contour maps from SURFER software. The degree of spatial dependence (GDE) was classified based on the nugget effect and the threshold ($C_0/C_0 + C_1$), which were considered weak above 75%, moderate between 25% and 75%, and strong below 25%[8].

The effects of the different soils were also verified using a multivariate analysis of variance (MANOVA). The similarity between the systems was verified by the cluster using the unweighted pair group method with arithmetic mean (UPGMA) method based on the Mahalanobis distance. To assess the contribution of each soil chemical variable in the cluster, an importance analysis of the variables was performed[9]. The analyses were performed using R (version 4.0.2; Cran, 2020) with the biotools package[10].

RESULTS AND DISCUSSION

Regardless of the analyzed samples, no differences were observed between the culture systems (Table 1) ($p < 0.05$) for pH, Na^+, and H + Al at the two depths of the soil samples (0–0.20 and 0.20–0.40 m). Variations between the different cultivation systems were observed for the levels of Ca^{2+}, Mg^{2+}, BS, CEC, V%, and Al^{3+} at both depths. Differences in the contents of SOM and K^+ were observed only at depths of 0–0.20 m and P at depths of 0.20–0.40 m.

Cassava cultivation showed the lowest SOM value at a depth of 0–0.2 m (Table 1), indicating it is the most degrading cultivation system. The lowest Ca^{2+} values, 0.9, 0.8, and 0.6 $cmol_c\ dm^{-1}$, recorded in cassava, pasture, and native vegetation, respectively, allow us to discriminate cropping systems in terms of Ca^{2+} exhaust capacity. Thus, considering SOM as a primary indicator and Ca^{2+} as secondary, the following sequence of degradation of cropping systems can be seen: cassava > native vegetation > pasture > secondary vegetation = pigeon pea. There was also a decrease in exchangeable bases between depths 0–0.2 m and 0.2–0.4 m, except for native vegetation, which varied from 0.6 m at superficial layer to 1.2 m at deepest. It can be hypothesized that greater water infiltration occurs in native vegetation with consequent Ca^{2+} leaching.

As shown in Table 1, the CV indicates the spatial distribution of the chemical attributes. Additionally, Table 1 shows a homogeneous distribution for pH values at a depth of 0-0.20 m and H + Al and CEC at a depth of 0–0.20 and 0.20–0.40 m, respectively, with the CV less than 12%. There was a heterogeneous distribution for pH (0.20–0.40 m), SOM, P, K^+, Na^+, Ca^{2+}, Mg^{2+}, BS, V%, and Al^{3+} at both depths with the CV between 12% and 60%[7]. The process of soil formation combined with successive and irregular management practices causes changes in chemical attributes, mainly in the superficial layers[11].

Table 1. Average soil chemical attributes in Chapada do Araripe in the municipality of Moreilândia, a semiarid area in the state of Pernambuco.

Analysis	pH	SOM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	H + Al	BS	CEC	Al^{3+}	V
	H_2O	g dm^{-3}	mg dm^{-3}					---- $cmol_c$ dm^{-1} --				%
Depth 0–0.20 m												
Secondary vegetation	4.0ns*	2.5a***	2.7ns	0.1b	0	1.3a	0.3a	4.8ns	1.6a	6.6a	0.88b	24.8a
pigeon pea	4.1ns	2.7a	2.8ns	0.4a	0	1.4a	0.1bc	4.4ns	1.6a	5.9a	0.89b	22.9a
Cassava	4.2ns	1.8b	2.3ns	0.1b	0	0.9b	0.1c	4.6ns	1.4a	5.9a	0.99ab	20.9ab
Pasture	3.9ns	2.3a	2.8ns	0.1b	0	0.8bc	0.2b	4.7ns	1.1ab	6.1a	1.21a	16.7ab
Native vegetation	4.1ns	2.6a	2.0ns	0.1b	0	0.6c	0.2b	4.3ns	0.7b	4.9b	0.75b	14.5b
CV**	9.5	24.8	27.6ns	30.9	0	21.7	31.3	11.2ns	34.5	11.4	24.48	32.5
Depth 0.20–0.40 m												
Secondary vegetation	3.9ns	1.4ns	2.8ab	0	0	0.7b	0.1a	4.9ns	0.8b	5.7ab	1.30ab	14.8b
pigeon pea	4.1ns	1.9ns	2.7ab	0	0	0.8b	0.1a	4.9ns	0.9b	5.9ab	0.97b	15.0b
Cassava	3.9ns	1.8ns	3.7a	0	0	0.8b	0.1a	4.3ns	0.9b	5.2b	1.13b	18.0b
Pasture	4.1ns	1.7ns	2.4b	0	0	0.8b	0.1b	4.6ns	0.9b	5.9ab	0.98b	15.8b
Native vegetation	3.6ns	1.9ns	2.3b	0	0	1.2a	0.1a	4.6ns	1.4a	6.4a	1.47a	23.1a
CV	12.0	26.8	28.9	0	0	20.2	36.3	11.9	21.2	11.7	24.17	16.9

The same letters in the same column do not differ statistically according to Duncan's test at p <0.05% probability. *ns, not significant by ANOVA F test; **CV, coefficient of variation. *** means followed by a master letter do not differ statistically.

The areas with pigeon pea (depth of 0–0.20 m) showed the highest levels of SOM (2.7), K^+ (0.4), and Ca^{2+}(1.4). The accumulation of SOM is a consequence, in most cases, of plant debris, which may increase in systems with less soil disturbance[12]. It is possible to consolidate this theory in the present work if we compare these levels detected in soils cultivated with cassava (1.8) that use soil tillage practices with plowing and harrowing in relation to the other areas.

Lower levels of K^+ are due to high acidity, so that soils with low pH values have increased K^+ leaching[13]. Another factor is the reduced CEC value; soils with high CEC provide greater adsorption and availability of K^+[14]. The reduced levels of Ca^{2+} and Mg^{2+} in the soils of Chapada do Araripe may be associated with the predominance of medium texture sandy soils, with low levels of organic matter and leachate, as highlighted by[15].

The highest values of P (3.7) were observed in the areas cultivated with cassava at a depth of 0.20–0.40m. The manure application process increases the levels of P in the soil, with a deep transfer of P incorporated into the soil surface, enhanced by the cultivation of cassava[16]. Regardless of the type of land use and the depth of sample collection, the BS values were low, showing that the exchangeable bases present in the soils were found in small quantities with higher averages in the secondary vegetation areas 1.6 (0–0.20 m) and native vegetation 1.4 (0.20–0.40 m).

Higher CEC values were observed in the areas of secondary vegetation (6.6) at a depth of 0–0.20 m) and native vegetation (6.4) at a depth of 0.20–0.40 m. Average CEC values were between 5 and 15 $cmol_c\ dm^{-3}$[17]. These average CEC levels can be associated with the organic matter content in the areas. The contribution of organic matter is greater than that of clays in soils that predominate pH-dependent loads because of the carboxylic and phenolic groups[3].

In the areas of secondary vegetation (24.8) and native vegetation (23.1) at depths 0–0.20 and 0.20–0.40 m, respectively, the highest values of V% were recorded, indicating low fertility. The highest average was recorded for Al^{3+} at a depth of 0–0.20 m (1.2) for pasture cultivation and 0.20–0.40 m for native vegetation (1.5). The soil class (Oxisol) of Chapada do Araripe presents a greater predominance of high levels of Al^{3+} and a reduction in negative charges due to increased weathering, as reported in the literature[14].

The adjustment parameters for the semivariograms were determined and are listed in Table 2. The Gaussian and spherical models were the best fit, except the V% at a depth of 0–0.20 m, which best fit the exponential model. For the variables, pH, SOM, Na^+, H + Al and Al^{3+}, at a depth of 0–0.20 m and SOM, P, K^+, Na^+, Mg^{2+}, BS, CEC, V%, and Al^{3+} at a depth of 0.20–0.40 m, it was not possible to obtain adjustments in semivariograms, resulting in the pure nugget effect.

Table 2. Models and parameters of the semivariograms, adjusted for the chemical attributes of the soil in Chapada do Araripe in the municipality of Moreilândia, a semiarid area of the state of Pernambuco.

Attribute	Model	C_0	C_0+C_1	Reach (m)	GDE (%)	R^2	N	NPR
				Depth 0–0.20 m				
pH	---	EPP	---	---	---	---	---	---
SOM	---	EPP	---	---	---	---	---	---
P	Spherical	0.01	0.28	1990	3.57	19	70	0
K^+	Spherical	0.0001	0.001	3530	0.10	52.9	70	0
Na^+	---	EPP	---	---	---	---	---	---
Ca^{2+}	Gaussian	0.13	0.49	4537	26.53	63	70	0
Mg^{2+}	Gaussian	0.01	0.41	6495	2.04	26	70	0
H + Al	---	EPP	---	---	---	---	---	---
BS	Spherical	0.09	0.68	5250	13.23	73	70	0
CEC	Gaussian	0.77	1.68	7707	45.83	50	70	0
V%	exponential	31.40	107.50	5460	21.20	62	70	0
Al^{3+}	---	---	---	---	---	---	---	---
				Depth 0.20–0.40 m				
pH	Gaussian	0.0001	0.024	987.25		54	69	1
SOM	---	EPP	---	---	---	---	---	---
P	---	EPP	---	---	---	---	---	---
K^+	---	EPP	---	---	---	---	---	---
Na^+	---	EPP	---	---	---	---	---	---
Ca^{2+}	Gaussian	0.09	0.87	32753		33.5	69	1
Mg^{2+}	---	EPP	---	---	---	---	---	---
H + Al	Gaussian	0.001	0.35	1160		66	70	0
BS	---	EPP	---	---	---	---	---	---
CEC	---	EPP	---	---	---	---	---	---
V%	---	EPP	---	---	---	---	---	---
Al^{3+}	---	EPP	---	---	---	---	---	---

EPP: pure nugget effect; GDE: degree of spatial dependence [GDE% = $(C_0 / C_0 + C_1) \times 100$]; R^2: coefficient of model determination; N: number of samples, NPR: Outline; number of points removed; BS: sum of bases (BS = $Ca^{2+} + Mg^{2+} + K^+$); CEC: cation exchange capacity (CEC = SB + H + Al); BS: baseline saturation [V% = (BS/CEC) × 100].

The occurrence of the nugget effect (C_0) allows a better understanding of the variability of the analyzed attributes, indicating the variance between the data[18]. In this work, the highest value was obtained for the variable V%, the lowest for the attributes P, K^+, Ca^{2+}, Mg^{2+}, BS, and CEC at 0–0.20 m and pH, Ca^{2+}, and H + Al at 0.20–0.40 m, indicating low variability in the samples (Table 2). These results indicate that the sampling distance recommended in this study was sufficient to indicate and identify the variability of the chemical attributes of the soil[8], except for the variables that obtained EPP at both depths, which indicates the need to collect samples at shorter distances.

The stationarity of the results was identified by the threshold ($C_0 + C_1$), as depicted in Table 2. The variance values showed an amplitude of 0.0001 and 31.40 for K^+ and V%, respectively, at a depth of 0–0.20 m, and the amplitude was between 0.0001 for pH and

0.09 for Ca^{2+} at a depth of 0.20–0.40 m. These data show that among these values, the stationarity is real and contributes to the definition of the spatial variability of the sampled points[19]. Thus, these results indicate that the models adjusted for chemical attributes have a plateau, and after a specific value, the distance between the points is no longer spatially dependent.

The range between the evaluated data showed values between 1990 m for P and 7707 m for CEC at a depth of 0–0.20 m and between 987.25 for pH and 32753 for Ca^{2+} at a depth of 0.20–0.40 m. Agronomic practices with the interest of homogenizing the cultivation area directly reflect the reach values[11]. The main parameter promoted by the geostatistical technique is the reach it has to monitor the performance of the analyzed variables, with a view to sustainable agriculture[17]. This range of geostatistical techniques is an important parameter in the study of spatial variability as it ensures that all points within a circle with the same radius are so similar that they can be used to estimate values for any point between them[20-21].

The distribution of these attributes in space is not random with respect to the degree of spatial dependence (GDE %). In our study, there was predominantly strong dependence for the attributes P (3.57%), K^+ (0.10%), Mg^{2+} (2.04%), BS (13.23), and V% (21.20%), with the exception of Ca^{2+} (26.53%) and CEC (45.83%) at a depth 0–0.20 m. The strong spatial dependence reflects the intrinsic properties of the soil, such as texture and mineralogy, whereas those with moderate or weak dependence are influenced by external factors, such as fertilizer application, preparation, and plant cultivation[8,19,20].

The highest values of the spatial determination coefficients (R^2) for the depth 0–0.20 m were observed in the attributes BS (73%), Ca^{2+} (63%), V% (62%), K^+ (52.9%), CEC (50%), Mg^{2+} (26%), and P (19%) of the soil. The potential acidity H + Al (66%), pH (54%), and Ca^{2+} (33.5%) had the highest R^2 values observed at a depth of 0.20–0.40 m. In general, the analysis of R^2 indicates the relationship between the real value and the value obtained by models, where values closer to 1 indicate better dependency. Our data corroborate the results reported by[4], who evaluated the spatial variability of soil attributes in rice fields and obtained a high degree of the dependent variable by independent variables.

Based on the results of the semivariograms, it was possible to make maps of the spatial distribution of the chemical attributes P, K^+, Mg^{2+}, BS, V%, and CEC at a depth of 0–0.20 m and pH, Ca^{2+}, and H + Al at a depth of 0.20–0.40 m (Figure 3). The construction of kriging maps makes it possible to identify the areas with greater and lesser variability in relation to the attributes, allowing the correct use of agricultural inputs to meet the needs of the soil and plant relationship[20].

In Figure 1, the closed lines on the maps identify areas with greater spatial variability. Therefore, the geostatistics technique enabled identifying places with greater and lesser variability through interpolation using kriging. It was also observed that the pH of the soil (0.20–0.40 m) of the studied area was classified as having very high acidity (<4.5). In general, this situation hinders the development and growth of the culture since the ideal pH would be between 5.5 and 6.5[21,22].

At a depth of 0–0.20 m, the levels of P varied between 1 and 4.6 mg dm^{-3} (Figure 3), with values for most cultures being very low[22]. This result must be associated with the soil characteristics in the region and the lack of incorporation of agricultural inputs (fertilizers). In addition, this nutrient is poorly mobile in the soil, indicating an urgent need for phosphorus applications in the region. The lack or low availability of these nutrients causes a drastic decrease in crop production[23]. The results showed less spatial variability of K^+ at a depth of 0–0.20 m, ranging from 0.015 to 0.127 $cmol_c\ dm^{-3}$, classified as very low and low, respectively. Values below 0.1 $cmol_c\ dm^{-3}$ indicate the need for a quick and precise application of potassium to supply the need for culture[21,24].

The Ca^{2+} in the studied area had low levels (0.5 to 2.5 $cmol_c\ dm^{-3}$) at both depths (Figure 1). This result confirms the acidity of the region's soil, requiring the application of corrective agents to increase these concentrations and consequently decrease the acidity of the soil. It should be noted that Ca^{2+} is an element of low mobility within the plant and must be homogeneously distributed in the soil, as its deficiency in the meristematic regions of the roots can impose severe restrictions on root development[11].

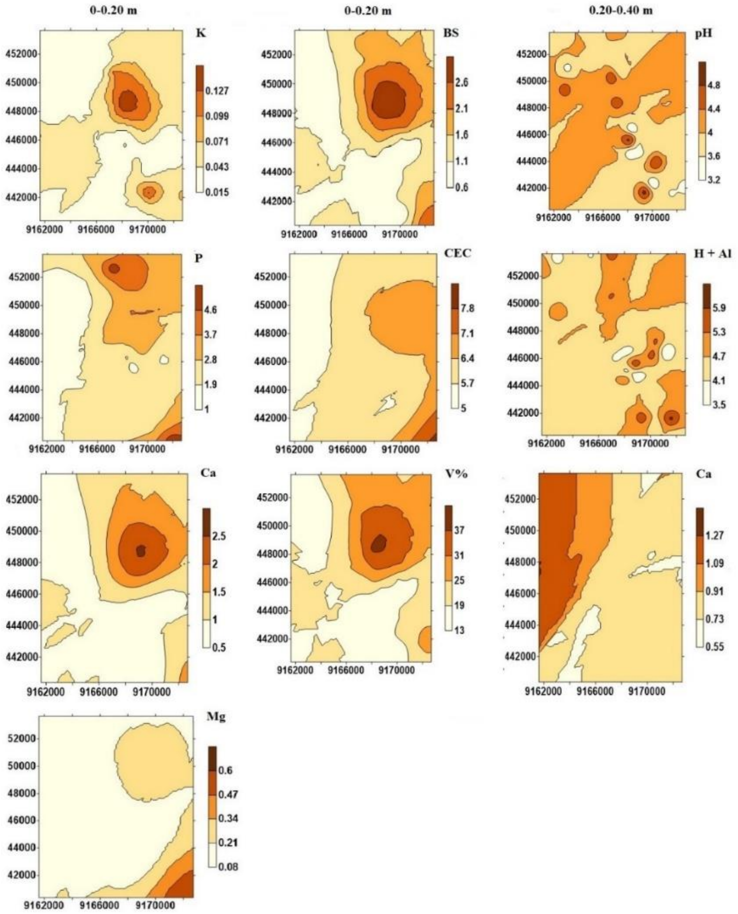
The Mg^{2+} contents were very low (0.08 to 0.6 $cmol_c\ dm^{-3}$) at a depth of 0–0.20 m (Figure 1), demonstrating an urgent need to correct these soils with dolomitic limestone. The values of H + Al were intermediate (3.5 to 5.9 $cmol_c\ dm^{-3}$)[22]. H + Al values below the average classification indicate that the cultivated area has toxicity problems, inhibiting the development and growth of the crops, mainly of the roots, hindering the availability of nutrients in the soil-plant relationship[25].

The values of BS, CEC, and V% showed variability at a depth of 0–0.20 m (Figure 3). These analyzed variables allow a new classification of soil fertility since it is the sum and percentage of participatory bases in relation to the exchange of soil cations. BS presented levels classified as low (0.06 to 2.6 $cmol_c\ dm^{-3}$) and with great variability throughout the area, suggesting that these values result from the non-incorporation of dolomitic limestone (rich in bases such as Ca^{2+} and Mg^{2+}) as well as a possible K^+ deficiency at adequate levels or loss by leaching due to its mobility in the soil.

The soil CEC result was classified as low (5.00 to 7.8 $cmol_c\ dm^{-3}$). The low CEC in the soil is likely related to the low values of the sum of bases and the low amount of organic matter present in the soil. The lack or low amount of organic matter in the soil makes it difficult to generate negative charges that benefit nutrient availability[25]. The authors of this study also emphasize that it is important to analyze the CEC values with respect to fertility because it indicates the capacity of the soil to adsorb cations in an exchangeable form, where they will generally serve as nutrients for plants.

The V% also presented values classified as low (13%–37%), as reported by other authors[23]. The studied area has low fertility (V% <50%), meaning the adopted soil management does not improve the availability of nutrients for the planted crop. Conversely, the spatial visualization of the distribution of V% values may allow adjustment of the fertilizing and liming practices.

Figure 1. Spatialization maps of the chemical attributes of the soil in Chapada do Araripe in the municipality of Moreilândia, a semiarid area of the State of Pernambuco.



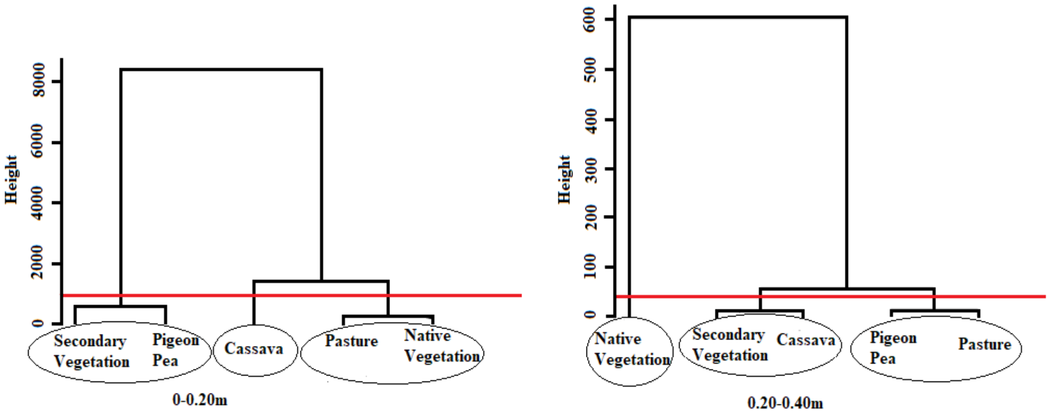
The results of the multivariate analysis of variance for the chemical attributes showed a significant difference (p <0.0001) between the cultivated areas according to Pillai's criterion at both depths (Table 3), which confirms the mapping of the areas carried out in the field.

Table 3. Results of the chemical attributes of the soil in Chapada do Araripe in the municipality of Moreilândia in the semiarid area of the state of Pernambuco.

Depth (m)	Criterion	Statistic	Approximation of F	*p*-value
0–0.20	Pillai	2.56	2.88	<0.001
0.20–0.40		2.71	3.39	<0.001

The multivariate hierarchical cluster analysis indicated the formation of agglomerates for the chemical attributes in the different areas managed at different depths of the soil (Figure 2). The clusters showed a co-phenetic correlation of 0.76 and 0.96, respectively, indicating a good ordering of the culture systems in the cluster, and the similarities between them can be interpreted.

Figure 2. Dendrogram of the hierarchical cluster analysis for different areas managed in Chapada do Araripe in the municipality of Moreilândia at different depths of the soil.



At a depth of 0–0.20m, three different groups could be categorized: (i) secondary vegetation and pigeon pea, (ii) cassava, and (iii) pasture and native vegetation. The Ca^{2+} content contributed to 97% of the differentiation between the systems, followed by the K^+ content and the BS (Table 4). The secondary vegetation and pigeon pea systems had the highest levels of Ca^{2+}, and the group formed by native vegetation and pasture had the lowest levels of this nutrient.

Table 4. Relative contribution of soil chemical attributes in calculating the Mahalanobis distance for different managed areas in Chapada do Araripe in the municipality of Moreilândia-PE at different soil depths.

0–0.20 m		0.20–0.40 m	
Variable	Proportion	Variable	Proportion
Ca^{2+}	0.9762	Ca^{2+}	0.4748
K^{+}	0.0075	V%	0.3011
BS	0.0048	$Ca^{2+}+ Mg^{2+}$	0.0744
V%	0.0023	BS	0.0447
P	0.0022	K^{+}	0.0246
CEC	0.0014	Al^{3+}	0.0211
Others	0.0056	Others	0.0593

The formation of three clusters was observed at a depth of 0.20–0.40 m that was different from those observed for the depth of 0–0.20 m. This allowed us to infer a difference between the levels of nutrients present at both depths[16], demonstrating the influence of soil depth on nutrient availability. The groups were clustered as (i) native vegetation, (ii) secondary vegetation and cassava, and (iii) pigeon pea and pasture. In addition to Ca^{2+} (47.48%), V% (30.11%), and Ca^{2+} + Mg^{2+} (7.44%) contributed considerably to the formation of agglomerates (Table 4). It is important to highlight that the native vegetation was isolated in the group, presenting the highest averages for Ca^{2+} and V%, since it has not been conditioned to the use of agricultural practices that induce changes in the chemical properties of the soil when not carried out correctly.

CONCLUSIONS

The findings of this work allow us to conclude that the areas studied in Chapada do Araripe, Moreilândia-PE present alterations in the chemical indicators of soil quality under different uses due to anthropic action.

The analyzed soils in the native vegetation had low natural fertility, and in the cultivated areas, the nutrients did not suffer any contribution from the extracted levels.

The analyzed soils have high acidity, indicating the need for pH correction to provide the best development of cassava, pigeon pea, and pasture crops.

ACKNOWLEDGMENTS

We would like to thank, Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Capes, Federal University of the São Francisco Valley, Institute of the Sertão Pernambucano, Rural Area Campus Petrolina, Federal University of Triângulo Mineiro, State University of Piauí, Federal University of Piauí and Editage (www.editage.com) for English language editing.

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