RESEARCH ARTICLE

# Soil attributes and their interralationships in Rio Grande do Sul

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## ABSTRACT

The present study aimed to highlight and understand the dynamics of interaction of the levels of soil parameters that are determinant for the expression of crop productivity. The study took place in seven municipalities in the northwest of the state of Rio Grande do Sul (Barra do Guarita, Braga, Derrubadas, Miraguaí, Redentora, Tenente Portela, and Vista Gaúcha), in the year 2017/2018. Soil samples were collected in these environments, with a total of 67 soil samples. Most of the studied soils presented pH above 5,5 with 79% of the samples with CEC between 12 and 18. The values of base saturation in 82% of the soils presented values of 80%, while, for of aluminum saturation, in 87% of the samples the values were 0. As for the contents of organic matter, 60% of the soils presented contents above 2,5% with high and low levels of potassium and phosphorus, respectively. When the levels of potential acidity increase, consequently, there is a reduction in the availability of the main nutrients, micronutrients and the Ca:K ratio. On the other hand, when there is an increase in pH levels, there is a greater availability of nutrients and a reduction in potential acidity and aluminum levels.

**Keywords**: Organic matter, nutrients, base saturation, effective CTC, use of resources, dynamics of the environments.

## INTRODUCTION

According to the linear increase in the world population, the expectation that the demand for food will increase in parallel with the number of people, which implies the need to increase food production in the coming years, having as one of the main strategies to meet future demands by food, increasing the productive efficiency of the species of interest. To achieve this objective, it is essential to understand the interaction between genotypes x environments, that is, to infer about the differential responses of genotypes to different environments in order to promote greater efficiency in the use of resources (Borém & Miranda 2009).

For this, it is essential to understand the dynamics of the environments with the insertion of the genotypes, evidencing the magnitude, concentration and relationships between the attributes that characterize an environment. These can be numerous, such as soil attributes, meteorological variables, disease incidence trends, among other factors.

Soil dynamics is one of the factors that can greatly limit the productivity of a crop, where this negative impact can be measured through parameters obtained through physical and chemical analysis of the soil, such as texture, depth, acidity, levels of chemical elements. These results, when performed in various environments, allow inferring about the fertility levels of a soil on a regional scale.

There is a great lack of information that gathers the attributes of the soil and its tendencies for the Northwest Region of the State of Rio Grande do Sul. In this sense, the present study aimed to highlight and understand the dynamics of interaction of the levels of soil parameters that are determinant for the expression of crop productivity.

## MATERIAL AND METHODS

The study took place in seven municipalities in the northwest of the state of Rio Grande do Sul (Barra do Guarita, Braga, Derrubadas, Miraguaí, Redentora, Tenente Portela, and Vista Gaúcha), in the year 2017/2018. Soil samples were collected in four areas of Barra do Guarita, three in Braga, twelve in Derrubadas, nine in Miraguaí, eleven in Redentora, thirty-five in Tenente Portela and two in Vista Gaúcha, with predominant occurrence of latosols and chernosols in these environments (Table 1).

**Table 1.** Description and geographic coordinates of the seven collection environments.

| Envirornment | Geographic Coordinates | | Altitude (m) | | | Total Prec. | Soil |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | T Mín[1] | T Máx[2] | | Mean clay content |
| **Barra do Guarita** | 27°11'28.27"S | 53°42'40.66"W | 194 | 14.68 | 25.56 | 6622.71 | 36.0% |
| **Braga** | 27°36'52.40"S | 53°44'23.47"W | 572 | 14.68 | 25.56 | 6622.71 | 76.0% |
| **Derrubadas** | 27°16'48.40"S | 53°51'23.21"W | 430 | 14.76 | 25.49 | 6734.41 | 54.9% |
| **Miraguaí** | 27°29'24.04"S | 53°41'24.43"W | 488 | 14.68 | 25.56 | 6622.71 | 68.0% |
| **Redentora** | 27°39'41.96"S | 53°38'25.76"W | 680 | 14.68 | 25.56 | 6622.71 | 63.2% |
| **Tenente Portela** | 27°22'18.50"S | 53°45'30.36"W | 390 | 14.68 | 25.56 | 6622.71 | 46.1% |
| **Vista Gaúcha** | 27°17'23.85"S | 53°42'9.83"W | 497 | 14.68 | 25.56 | 6622.71 | 64.5% |

[1]Tmin – Minimum Air Temperature. [2]Tmax – Maximum Air Temperature.

To collect the samples, the total area was subdivided into smaller plots and with greater homogeneity within the plots. Subsamples were collected within the plot, with a depth of 0 – 20 cm, where they were homogenized and a composite sample was performed. Samples from each environment were identified and analyzed in the soil laboratory of the Universidade Regional do Noroeste do Rio Grande do Sul. The attributes evaluated in the soil samples were: clay content (clay, %), hydrogen potential (pH, unit), SMP index (SMP, unit), effective CEC (effective CEC, cmolc $kg^{-1}$), base saturation (V, %), potential acidity (H +Al, cmolc $dm^3$), aluminum saturation (M, %), organic matter (OM., %) phosphorus (P, mg $dm^3$), potassium (K, mmolc $dm^3$), aluminum (Al, mg $dm^3$), calcium (Ca, mmolc $dm^3$), magnesium (Mg, mmolc $dm^3$), sulfur (S, mg $dm^3$), zinc (Zn, mg $dm^3$), copper (Cu, mg $dm^3$), boron (B, mg $dm^3$) and manganese (Mn, mg $dm^3$), calcium-magnesium ratios (Ca:Mg, unit), calcium:potassium (Ca:K, unit) were also measured. and potassium:magnesium (Mg:K, unit).

A descriptive analysis of the data was carried out through simple relative or absolute frequency distributions of soil attributes. The assumptions of normality were analyzed using Shapiro Wilk test, homogeneity of residual variances using Bartlett test. Thus, the data obtained were submitted to analysis of variance at 5% of significance by the F test in order to verify differences for carrying out the Euclidean grouping. Subsequently, in order to understand the linear associations between the characters, linear correlations were carried out through *Pearson's* linear correlation, where the level of significance of the coefficients was obtained by the t test at 5% of significance.

In order to identify patterns to show which measured characters are associated, the Artificial Neural Networks (ANNs) approach was used, basing their estimates through unsupervised computer learning, through the Kohonen map, it was carried out with the aim of identifying possible groups of lineages and which of these variables (neurons) could be the determinants for the discrimination of centroids (groups).In addition, the study of divergence between soil samples was carried out through cluster analysis using the Euclidean distance as a measure of dissimilarity. After obtaining the Euclidean distance matrix, the UPGMA clustering method was used to generate the dissimilarity dendrogram in order to recognize homogeneous groups. Statistical analyzes were performed using the R software (R Core Team, 2022).

## RESULTS AND DISCUSSION

Using the simple or absolute relative frequency distribution, it was possible to evidence the formation of soil classes. As can be seen in Figure 1A, the clay content data (Clay, %) were distributed into seven classes, with an amplitude of 72%, minimum and maximum values of 18% and 90%, respectively. It is observed that more than 50% of the soil samples present contents equal to or greater than 52% of clay, which means that the soils in this region suffered a greater weathering process. The clay content of the soil can influence the relationship with nutrients, changing the phosphorus adsorption capacity, due to the high content of oxides in this fraction, mainly in latosols (Vinha, Carrara, Souza, Santos, & Arantes, 2021).

The hydrogen potential (pH) was equal to or greater than 6,15 in 43% of the samples. On the other hand, approximately 56% of the analyzes present pH values lower than or equal to 5,85 (Figure 1B), a value that may prove to be a limiting factor for the ideal development of plants to occur (Brignoli, Souza Junior, Grando, Mumbach, & Pajara, 2020). Soil pH is responsible for controlling some soil reactions, in general, pH values between 5,5 and 6,5 are appropriate for the development of most plants. According to Yakuwa et al. (2020), soil acidity can be one of the main factors causing losses in the productivity of agricultural crops, and in soils with acidic pH there is a lower absorption of nutrients by plants, making soil correction necessary.

The SMP index (SMP, %) is indicative of the buffering capacity of the soil, used as a basis for liming in some soils (Brignoli et al., 2020). It can be seen that the SMP index was divided into seven classes, with an amplitude of 1,8 (Figure 1C). The highest concentration occurred where SMP values were equal to 6,45, with a frequency of 47,37%, followed by SMP contents of 6,2 and 5,8.

The cation exchange capacity (CEC, cmolc $kg^{-1}$) showed data dispersion from 9 to 33, where about 40.79% of the soils are concentrated in CEC 12, and approximately 79% of the frequency is between classes of 12 at 18 (Figure 1D). The cation exchange capacity (CEC) is the ability to retain and exchange cations in the soil due to electrostatic effects, these cations are constantly exchanged in the soil becoming available to plants, because of this it is assumed that soils with low CEC present lower fertility and water and nutrient supply capacity (Costa et al., 2019).

In Figure 1E it is possible to infer about the base saturation ratio (V, %), which had a variation of 56%, presenting a frequency of 43,42% with the value of V% above 80 and approximately 26% above of 88%. Base saturation is an important indicator of general soil fertility conditions, being used as a complement in genetic and technical soil classifications. When the V% index is low, it shows that the soil has a small amount of exchangeable cations and most likely this soil will be acidic, as it contains amounts of aluminum ($Al^{3+}$), which can end up becoming toxic and harmful to plant development (RONQUIN, 2010).

The potential acidity (H + Al, cmolc $dm^3$), represented in Figure 1F, shows an amplitude of 7,2 cmolc $dm^3$, showing a higher occurrence between 2,4 cmol $dm^3$ and 4,8 cmolc $dm^3$ around 97,37% of the samples, revealing that it is inverse to the SMP, due to the way it is estimated, using the value of the SMP index.

$Al^{3+}$ saturation (M, %) (Figure 1G) showed an amplitude of 36%. In 86.84% of the samples, the simple relative frequency was zero, and only 13,16% of the samples presented values greater than zero. In relation to the contents of organic matter (OM, %), where they present a dispersion of values that goes from 1 to 4. It was observed that 26,32% of the samples exhibited values of 2,5% of organic matter, while 73,68% of the areas were between classes 2 to 4 (Figure 1H). Phosphorus (P) levels, represented in Figure 1I, showed a great variation, with an amplitude of 56, occurring more frequently in 65,79% of the soils, at levels close to 4 mg $dm^3$.

The potassium levels (K, mmolc $dm^3$), represented in Figure 2A, reveal the occurrence of up to 600 mmolc $dm^3$, with the highest frequency in the class of 150 mmolc $dm^3$, with 48,68% of the samples. Still, 82,21% of the samples showed values greater than or equal to 50 mmolc $dm^3$. In relation to Aluminum (Al, mg $dm^3$), the values ranged from 0,3 to 3,9, with the highest frequency observed in the lowest class, that is, about 92% of the data presented a content of 0,3 (Figure 2B). This indicates that in most of the crops sampled, there is a concern with the control of aluminum levels, since high aluminum levels hinder the root development of crops and, consequently, the absorption of nutrients, directly affecting crop productivity (Rutkowska, Szulc, Hoch, & Spychaj-Fabisiak, 2014).

Regarding the calcium content (Ca, mmolc $dm^3$), values from 4,5 to 22,5 mmolc $dm^3$ were obtained (Figure 2C). Considered a macronutrient, the vast majority of the analyzed soils (40,79%) presented values of 7,5 mmolc $dm^3$, that is, in sufficient quantity for the plants. The magnesium contents (Mg, mmolc $dm^3$) varied from 1 to

8 mmolc dm³ for the samples (Figure 2D), where 39,47% of the analyzes obtained 3 mmolc dm³. There was a high occurrence for the values of 2 and 4 mmolc dm³, that is, respectively, 15,79% and 19,74% of the samples. Magnesium is considered a macronutrient, essential for plants and interferes with the absorption of other nutrients by the root system.

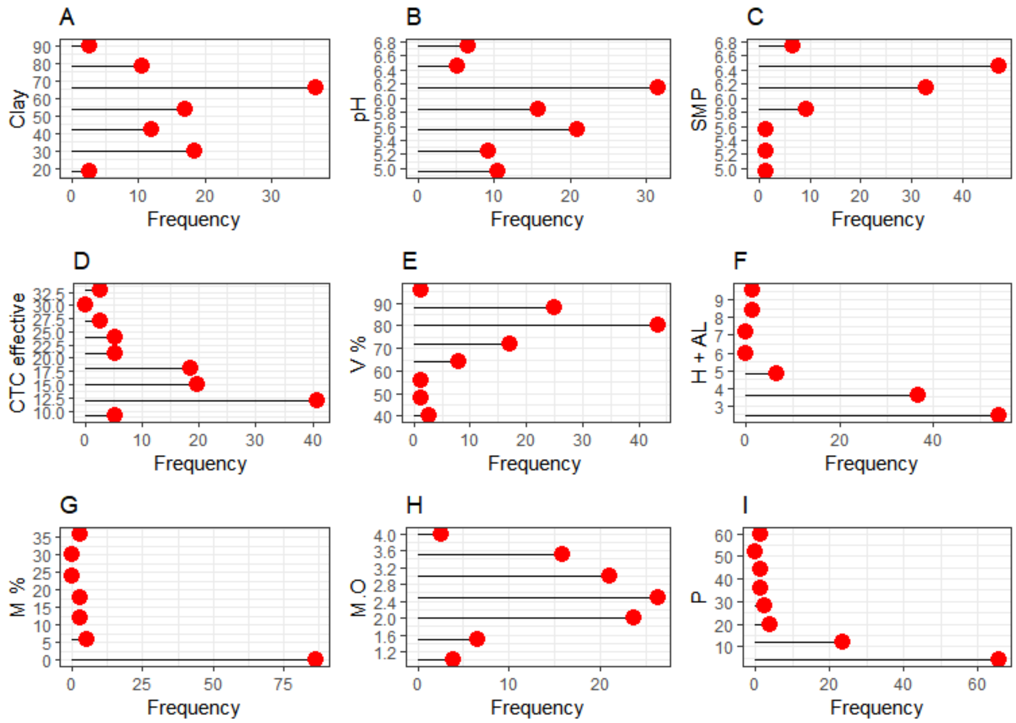


**Figure 1.** Clay simple or absolute relative frequency distribution analysis, pH (hydrogen potential), SMP (soil acidity analysis and correction method), effective CEC (effective cation exchange capacity), V% (base saturation), H+Al (potential acidity), M% (aluminium saturation), OM (organic matter), and P (phosphorus).

The sulfur contents represented by the analyzes (Figure 2E) presented the highest frequency at 6 mg dm³, with 44,74% of the samples. The highest simple relative frequency occurred between classes 6 and 12 mg dm³ with 76,32% and the amplitude of the samples was 42 mg dm³. The most frequent sulfur in the data occurred for a concentration of 5 to 10 mg dm³, with a frequency of 70% of the data, this is a macronutrient which helps to maintain the green color of plants, mainly due to its role in nitrogen metabolism, providing also for greater plant resistance and boosting plant growth.

The zinc contents of the collected samples, shown in Figure 2F, demonstrate a high data variability from 6 to 90 mg dm³, most soils present a value of 6 mg dm³, occurring in 57,89% of the samples. It is observed that 75% of the samples are between classes 6 and 18 mg dm³. The copper content (Figure 2G) shows a higher concentration of results equal to or less than 15 mg dm³, represented by 87,44% of the samples evaluated. The class with the highest frequency of samples was 15 mg dm³, with 38,16% of the results.

Boron (Figure 2H) presented an amplitude of 0,7 mg dm³, where the highest expression was at 0,2 mg dm³ with a frequency of 31,58% of the samples. Classes from 0,1 to 0,3 mg dm³ presented a frequency of 61,84% of the sampled areas. The manganese shown in Figure 2I shows a range of results of 60 mg dm³, with values from 0 to 20 mg dm³ being the most recurrent, with 73,68% of the samples. The highest frequency was 39,47% for the 10 mg dm³ class.

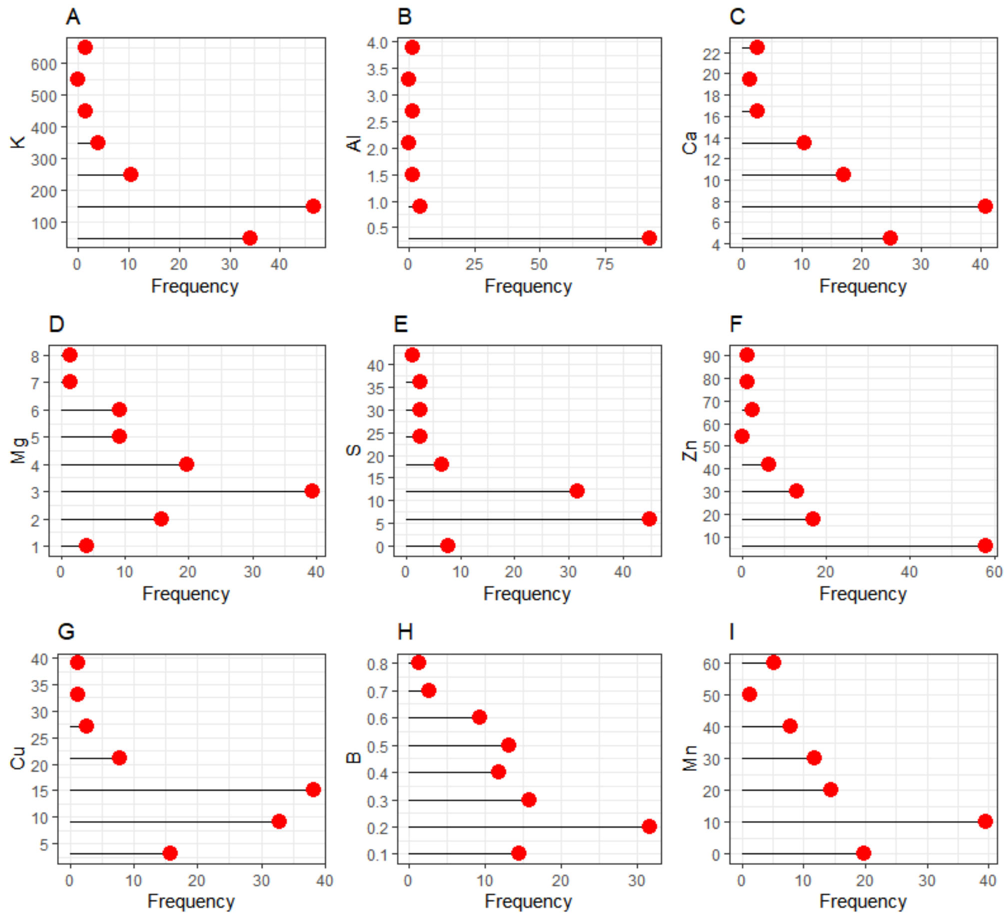


**Figure 2.** Simple or absolute relative frequency distribution analysis of K (potassium), Al (aluminium), Ca (calcium), Mg (magnesium), S (sulfur), Zn (zinc), Cu (copper), B (boron), and Mn (manganese).

In the relationship between calcium and magnesium contents (Figure 3A), it can be observed that there was a higher simple relative frequency for the value of 2,4, that is, for every 2.4 mmolc dm³ of calcium, there is 1 mmolc dm³ of magnesium, representing 32,89% of the analyses. It is observed that 74,99% of the samples are situated between classes 2 and 2,8. In the calcium and potassium ratio (Figure 3B), the amplitude was 140, with a higher frequency between classes 0 to 40, with 85.53%. The ratio of 20 mmolc dm³ of calcium to 1 mmolc dm³ of potassium was the most frequent, being in 60,53% of the samples. Figure 3C shows the ratio of magnesium and potassium, where the value most frequently was 9 mmolc dm³, representing that for every 9 mmolc dm³ of magnesium there is 1 mmolc dm³ of potassium, with this value being 42,11% frequency of samples. Classes from 3 to 15 mmolc dm³ concentrated 82,9% of the sample results.

The similarity dendrogram grouped the 76 samples into 12 groups (Figure 4). In the group formed by the samples 31TP, 25TP, 21TP, 18TP, 15TP, 12TP, 10TP, 7DE, 4DE and 4BG, there is an affinity when dealing with the variables pH, SMP, CEC, base saturation, potential acidity, Al saturation, Calcium, Zinc, Copper, Boron contents, Ca:Mg contents had similarity as well as Ca:K and Mg:K.

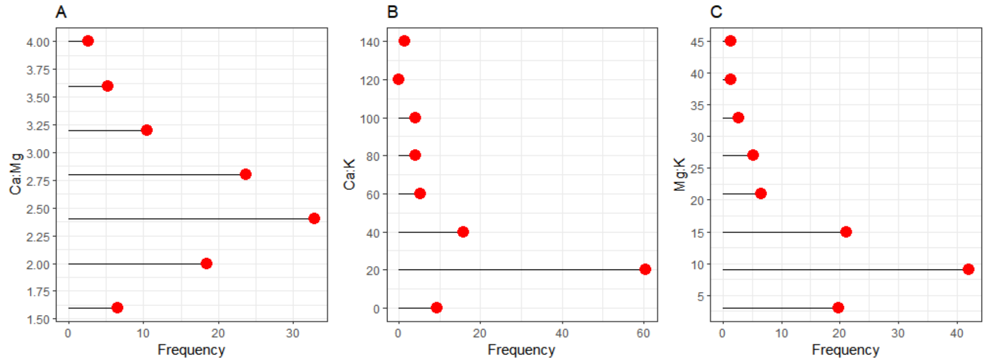


**Figura 3.** Simple or absolute relative frequency distribution analysis of Ca:Mg (calcium-magnesium ratio), Ca:K (calcium-potassium ratio), Mg:K (magnesium-potassium ratio).

In the grouping of samples 3BG, 6DE, 9DE, 10DE, 2MI, 1RE, 1TP, 3TP, 6TP, 17TP and 2VG, there is consistency, referring to clay content, SMP, base saturation, and pH. In the group formed by the samples 1BG, 2BG, 2TP, 5TP, 13TP, 14TP, 16TP, 19TP, it is observed that there is an affinity in the clay contents, SMP index, Base saturation, Boron content, and in the Ca: Mg. In the group of samples 11BR, 2BR, 3BR, 5DE, 11DE, 4MI, 11TP, 26TP, 27TP, 29TP, 30TP, 32TP, 1VG, there is a correlation between pH, CEC, base saturation, potential acidity, Al, and B. In sample 1DE, there was an emphasis on clay content, in relation to all other samples, the SMP index also a discrepancy in relation to the other 75 samples, as well as SMP, CEC and base saturation, the potential acidity was also highlighted in relation to the others. Ca and Mg contents were the highest in relation to the other 75 samples, and there was an absence of manganese.

In the group formed by samples 2DE, 8DE, 12DE, 9MI, 2RE, 3RE, 4RE, 6RE, 7RE, 8RE, 28TP, 34TP, there was similarity in the levels of SMP, CEC, Al, Mg and B. 4TP, an affinity was identified between clay contents, SMP index, potential acidity, Al saturation. The environments of samples 1MI, 5MI, 7MI, 8MI, 7TP, 20TP, 22TP, 23TP, 33TP, showed similarities between clay content, pH, SMP index, CEC, base saturation, Al saturation, Al content, B, as well as the Ca:Mg ratio. The 3MI and 6MI environments obtained similarity in aspects such as high clay content and being the highest of all samples, the pH also had a similarity, for Al saturation it is observed that it was the highest of all samples, as well as potential acidity.

The locations of samples 5RE, 9RE, 10RE, 24TP, had similar values in SMP, base saturation, potential acidity, Al saturation, organic matter content, Al, and B. The environments 11RE, 8TP and 9TP, presented for the contents of pH, SMP, potential acidity, organic matter, Ca and S, a similarity, as well as in the interaction between Ca and K. The location of sample 35 of Tenente Portela (35TP), stood out for having a low content of K and zinc and also by the greater interaction among the other samples in the Mg:K ratio.

According to the organization of the neural network, there are indications that in relation to the characteristics of the soils of each environment there is a grouping in 18 centroids, which differ from each other, however within each center there is a certain similarity between the attributes and characteristics of each environment. In centroid I, samples 5MI, 8MI, 2RE, 3RE, 5RE, 9RE, 10RE are grouped. In the centroid group II there is an affinity between eight samples formed by 8DE, 1MI, 7MI, 7RE, 8RE, 8TP, 20TP, 23TP. In centroid III, samples 4RE, 6RE, 27TP, 28TP, 34TP are correlated. In the same way that happens in centroid IV covering the environments 9MI, 7TP, 22TP, 26TP, 33TP.

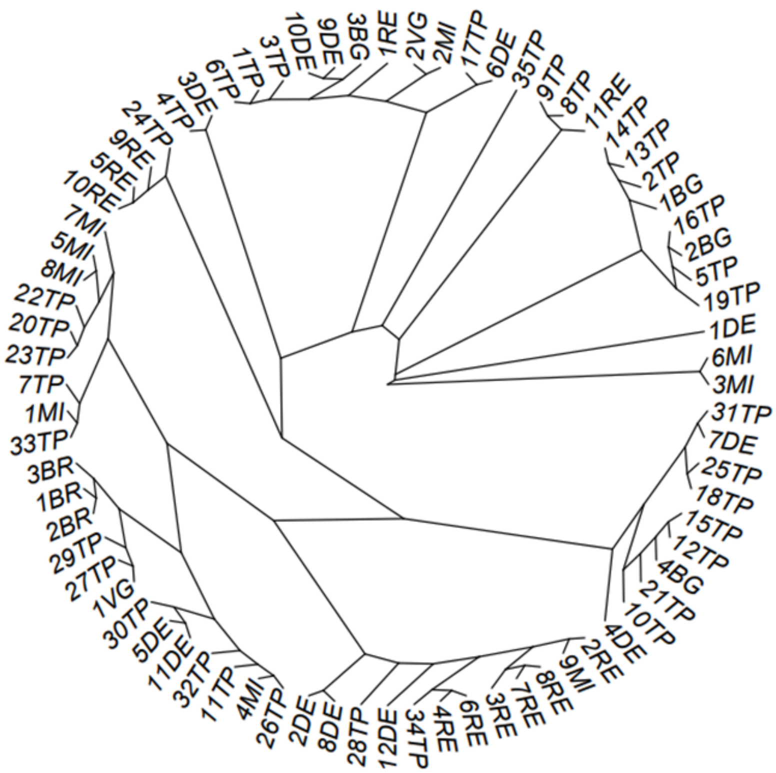


**Figure 4.** Similarity dendrogram obtained by the UPGMA clustering method of 76 soil samples from seven environments in the state of Rio Grande do Sul. BG: Barra do Guarita, BR: Braga, DE: Derrubadas, MI: Miraguaí, RE: Redentora TP: Tenente Portela, VG: Vista Gaúcha, preceded by the sample number.

Centroid V is composed of samples 12DE, 11RE, 29TP, 1VG, centroid VI is formed by samples 2DE, 9DE, 9TP. Centroid VII, consisting of 4DE, 18TP, 24TP, 25TP, 31TP, 32TP, in centroid VIII formed by 1BR,2BR, 3BR, 5DE, 11DE, 4MI, centroid IX composed of samples 3BG, 1RE, 1 TP, 3TP, 6TP, 17TP. Centroid X, formed by 7DE, 11TP, 30TP, in centroid XI, formed by samples 3DE and 2TP, centroid XII formed by samples 10DE and 35TP.

The formed centroid XIII is composed of 4BG, 1DE, 5TP, 12TP, 15TP, 21TP, centroid XIV, consisting of the sample 6DE, 2MI, 2VG. At centroid XVI, composed 2BG, 13TP, 14TP, 16TP, 19TP. Centroid XVII constituted only by sample 1 of Barra do Guarita (1BG), centroid XVIII formed by samples 3MI, 6MI, where there is a similarity in relation to pH values, SMP index, CEC, Al, organic matter (OM), saturation by bases, Al saturation, in addition to the Ca:Mg ratio. It is possible to observe that there is a discrepancy between the values of clay contents in most environments, except in centroids X, XI, XII, XIII, XIV, XV, XVI, XVIII, essential minerals such as phosphorus (P), potassium (K), sulfur (S), as well as micronutrients (Mg, Cu, B, Mn), similarly with the Ca:K and Mg:K ratio, varying according to the soil and region.

It is possible to observe the grouping of variables in different groups, using the variation of values as a parameter (Figure 5 and 6). For example, at CEC and Al, a discrepancy between the values of this variable in the environments can be observed, which will possibly characterize them. In view of the 76 environments, characteristics such as pH, SMP, H+Al, Mo, B, Mg, Al and Ca:Mg, P, Ca, S, Cu, K, clay, V% Ca:K ratio, Zn, Mn, CET, Mg:K, which are shown in the Figure 5, are grouped, which makes the 76 environments of the northwest region of Rio Grande do Sul similar.

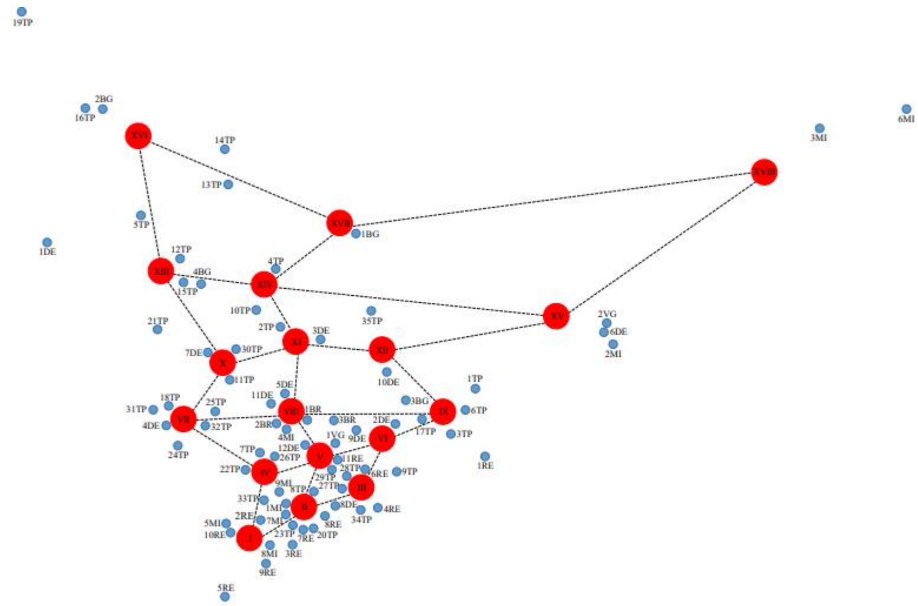

**Figure 5**. Clustering Kohonen map using a neural network of 76 soil samples obtained in seven environments in the state of Rio Grande do Sul. BG: Barra do Guarita, BR: Braga, DE: Derrubadas, MI: Miraguaí, RE: Redentora TP: Tenente Portela, VG: Vista Gaúcha.

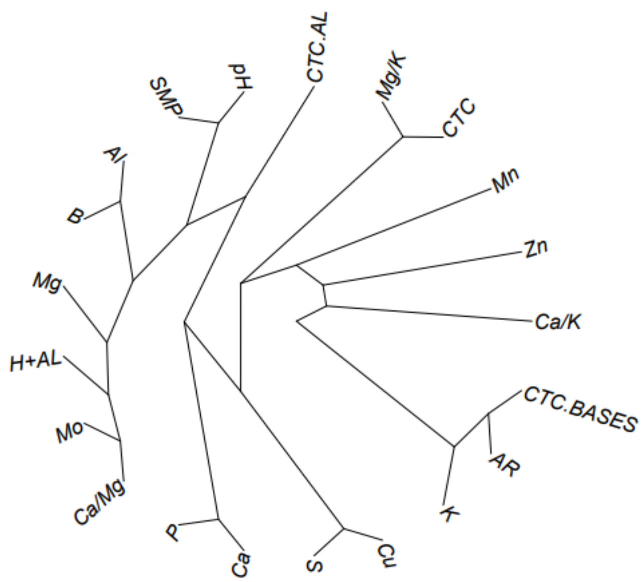


**Figure 6.** Dendrogram of similarity obtained by the UPGMA grouping method of the variables obtained in 76 soil samples in seven environments in the state of Rio Grande do Sul. clay: clay content, pH: hydrogen potential, SMP: SMP index, CEC: CEC effective V%: base saturation, H +Al: potential acidity, M%: aluminum saturation OM: organic matter, P: phosphorus content K: potassium content, Al: aluminum content, Ca: calcium content, Mg: magnesium content, S: sulfur content, Zn: zinc content, Cu: copper content, B: boron content, Mn: manganese content, Ca/Mg: calcium-magnesium ratio, Ca/K: calcium ratio potassium, Mg/K: magnesium-potassium ratio.

Table 2 shows *Pearson's* linear correlation, where it aims to understand the degree of association between soil characteristics. Thus, it can be seen that as the clay content of the soil increases, the levels of potential acidity (H+Al), aluminum saturation (M%), aluminum content (Al) and sulfur content (S) increase. since they present weak and moderate correlation, respectively. On the other hand, there is a decrease in the values of SMP index (SMP), calcium (Ca), magnesium (Mg), calcium/magnesium ratio (Ca:Mg), calcium/potassium ratio (Ca:K) and magnesium/potassium ratio. (Mg:K) due to weak, moderate, strong, moderate, weak, moderate and moderate negative correlation.

When the *Pearson's* correlation for pH is observed, when the pH is increased, there are increases for SMP, base saturation (V%), molybdenum (Mo) content, calcium (Ca), magnesium (Mg) and zinc content (Zn), due to the presence of strong, strong and weak correlations, respectively, there is still a reduction for the potential acidity index (H+Al), aluminum saturation (M%), aluminum content (Al), sulfur content (S) and for manganese (Mn) content resulting from the correlation obtained, being moderate for the other factors and strong for manganese. The correlation of SMP index (SMP) showed a positive correlation for base saturation (V%), molybdenum content (Mo), calcium content (Ca), magnesium content (Mg) and zinc content (Zn), increasing the their rates with their increase due to the presence of strong, weak, moderate, moderate and weak positive correlation, respectively, on the contrary, there was a strong negative correlation for all factors, these being the potential acidity index (H+Al), aluminum saturation (M %), aluminum content (Al), sulfur content (S) and manganese content (Mn).

The cation exchange capacity (CEC) when increased triggers an increasing correlation for the relationship cation exchange capacity and base saturation (V%), phosphorus content (P), calcium content (Ca), magnesium content (Mg), calcium:magnesium ratio (Ca:Mg), calcium/potassium ratio (Ca:K) and magnesium/potassium ratio (Mg:K), in the strengths of moderate, weak, strong, strong, weak, moderate and moderate correlations , conversely, when CEC is increased, there is a decrease for aluminum saturation (M%), sulfur content (S), boron content (B) and manganese content (Mn) with only weak correlations being obtained for the factors. Observing the base saturation (M%) there was a positive correlation for calcium content (Ca), magnesium content (Mg), zinc content (Zn), calcium/potassium ratio (Ca:K) and magnesium/potassium ratio (Mg:K) with strong, strong, weak and moderate content. A negative correlation was observed for the potential acidity index (H+Al), aluminum saturation (M%), aluminum content (Al), sulfur content (S) and manganese content (Mn) with strong correlations for the factors and moderate for manganese (Mn) content.

When the potential acidity (H+Al) increased, the increase in aluminum saturation (M%), magnesium content (Mg), zinc content (Zn), calcium/potassium ratio (Ca:K), magnesium/potassium ratio (Mg:K) was evidenced based on strong, weak, strong, strong and moderate correlations, respectively, as well as a decrease for molybdenum content (Mo), calcium content (Ca), magnesium content (Mg) and zinc content (Zn) in the weak, moderate, moderate and weak forces, respectively. Aluminum saturation (M%) showed a positive correlation for potassium content (K), aluminum content (Al), sulfur content (S) and manganese content (Mn), these correlations were weak, perfect, strong and moderate, respectively, in an opposite way, there was a negative correlation for molybdenum content (Mo), calcium content (Ca), magnesium content (Mg) and for magnesium:potassium ratio, in the weak, moderate, moderate and weak forces, respectively.

**Table 2**. Linear correlations of the variables analyzed in the 76 environments.

| | CC[1] | pH | SMP | CEC | CECAB | H+Al | CECAl | OM | P | K | Al | Ca | Mg | S | Zn | Cu | B | Mn | Ca:Mg | Ca:K | Mg:K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CC | . | -0.1 | -0.33*[2] | -0.7 | -0.61* | 0.37* | 0.43* | 0.18 | -0.23 | 0.11 | 0.40* | -0.75* | -0.68* | 0.50* | 0.04 | 0.21 | 0.19 | 0.15 | -0.27* | -0.53* | -0.41* |
| pH | | . | 0.78* | 0.21 | 0.67* | -0.67* | -0.52* | 0.28* | 0.1 | 0.04 | -0.48* | 0.31* | 0.38* | -0.51* | 0.25* | 0.02 | 0.08 | -0.70* | -0.13 | 0.03 | 0.08 |
| SMP | | | . | 0.22 | 0.85* | -0.96* | -0.81* | 0.32* | 0.06 | -0.22 | -0.81* | 0.41* | 0.43* | -0.72* | 0.27* | -0.13 | 0.07 | -0.65* | -0.01 | 0.16 | 0.19 |
| CEC | | | | . | 0.61* | -0.17 | -0.18 | -0.2 | 0.34* | 0.14 | -0.13 | 0.96* | 0.89* | -0.36* | -0.01 | -0.14 | -0.23* | -0.24* | 0.28* | 0.61* | 0.47* |
| CECAB | | | | | . | -0.84* | -0.81* | 0.22 | 0.2 | -0.15 | -0.76* | 0.74* | 0.75* | -0.78* | 0.24* | -0.07 | -0.02 | -0.59* | 0.1 | 0.42* | 0.39* |
| H+Al | | | | | | . | 0.90* | -0.34* | -0.07 | 0.35* | 0.92* | -0.38* | -0.40* | 0.74* | -0.25* | 0.09 | -0.1 | 0.53* | -0.02 | -0.19 | -0.22 |
| CECAl | | | | | | | . | -0.34* | -0.14 | 0.36* | 0.98* | -0.37* | -0.40* | 0.76* | -0.2 | 0 | -0.13 | 0.39* | 0.01 | -0.22 | -0.24* |
| OM | | | | | | | | . | 0.14 | -0.02 | -0.35* | -0.14 | -0.02 | -0.32* | 0.60* | 0.12 | 0.43* | 0.02 | -0.17 | -0.26* | -0.17 |
| P | | | | | | | | | . | 0.40* | -0.13 | 0.25* | 0.46* | -0.05 | 0.06 | 0.39* | -0.12 | 0.15 | -0.24* | -0.07 | -0.03 |
| K | | | | | | | | | | . | 0.45* | -0.03 | 0.11 | 0.36* | 0.11 | 0.30* | -0.1 | 0.02 | -0.26* | -0.49* | -0.52* |
| Al | | | | | | | | | | | . | -0.33* | -0.35* | 0.74* | -0.19 | 0 | -0.13 | 0.31* | -0.04 | -0.2 | -0.22 |
| Ca | | | | | | | | | | | | . | 0.85* | -0.52* | 0.02 | -0.2 | -0.2 | -0.34* | 0.39* | 0.67* | 0.51* |
| Mg | | | | | | | | | | | | | . | -0.45* | 0.12 | -0.03 | -0.17 | -0.30* | -0.09 | 0.46* | 0.47* |
| S | | | | | | | | | | | | | | . | -0.19 | 0.16 | -0.03 | 0.42* | -0.2 | -0.40* | -0.35* |
| Zn | | | | | | | | | | | | | | | . | 0.01 | 0.41* | -0.09 | -0.12 | -0.18 | -0.15 |
| Cu | | | | | | | | | | | | | | | | . | -0.01 | 0.27* | -0.18 | -0.34* | -0.30* |
| B | | | | | | | | | | | | | | | | | . | 0.04 | -0.08 | -0.19 | -0.14 |
| Mn | | | | | | | | | | | | | | | | | | . | 0.02 | -0.19 | -0.18 |
| Ca:Mg | | | | | | | | | | | | | | | | | | | . | 0.39* | LL0.06 |
| Ca:K | | | | | | | | | | | | | | | | | | | | . | 0.91 |
| Mg:K | | | | | | | | | | | | | | | | | | | | | . |

[1]CC: clay content, pH: hydrogen potential, SMP: SMP index, CEC: effective CEC V%: base saturation, H+Al: potential acidity, M%: AB: acid-base, aluminum saturation OM: organic matter, P: phosphorus content K : potassium content, Al: aluminum content, Ca: calcium content, Mg: magnesium content, S: sulfur content, Zn: zinc content, Cu: copper content, B: boron content, Mn: content of manganese, Ca/Mg: calcium-magnesium ratio, Ca:K: calcium-potassium ratio, and Mg:K: magnesium-potassium ratio. [2]*Significant at 5% probability by t test.

Pearson's correlation for molybdenum (Mo) content was moderately positive for zinc (Zn) and boron (B) content and negative for aluminum (Al), sulfur (S) and calcium/potassium ratio (Ca/ K) weakly. The phosphorus (P) content, when increased, caused a positive relationship for potassium content (K), calcium content (Ca), magnesium content (Mg) and copper content (Cu), being the relationships moderate, weak and moderate, respectively, oppositely weak correlation for calcium/magnesium ratio (Ca:Mg). The potassium (K) contents were positively correlated with the aluminum (Al), sulfur (S) and copper (Cu) content variables, moderately and weakly, respectively, and negatively correlated with the calcium:magnesium ratio variables (Ca:Mg), calcium/potassium ratio and magnesium/potassium ratio (Mg:K) in a weak and moderate way, respectively.

For aluminum (Al) content in the soil, there was a strong and weak positive correlation, respectively, when compared to sulfur (S) and manganese (Mn) content, as well as the opposite for calcium (Ca) and magnesium (Mg) in a weak form. When the levels of calcium (Ca) are correlated, there is an increase in the levels of magnesium (Mg), calcium/magnesium ratio (Ca:Mg), calcium:potassium ratio (Ca:K) and magnesium/potassium ratio (Mg:K), being strong and moderate correlations of forces, in that order, likewise, there was a moderate and weak negative correlation, respectively, for the variables sulfur content (S) and manganese content (Mn).

*Pearson's* correlations for magnesium (Mg) were positive and moderate for calcium:potassium ratio (Ca:K) and magnesium:potassium ratio (Mg:K), a moderate negative correlation was identified for sulfur content (S) and weak for manganese (Mn) content. The sulfur variable (S) showed a moderate positive relationship for the quantification of manganese (Mn), opposite to that, there was a moderate negative relationship for the calcium:potassium (Ca/K) ratio and weak for the magnesium/potassium (Mg:K) ratio. The correlation obtained for zinc (Zn) content showed a moderate positive relationship for boron content (B) and the correlation for copper (Cu) content was positive and weak for manganese and negative and weak for calcium/potassium (Ca:K) and magnesium/potassium ratio (Mg:K). The correlation of the values of the calcium/magnesium ratio (Ca:Mg) was positive and moderate for the calcium/potassium ratio (Ca:K). The other variables did not present significant correlations with each other.

## CONCLUSIONS

Most of the studied soils presented pH above 5.5 with 79% of the samples with CEC between 12 and 18. The values of base saturation (V%) in 82% of the soils presented values of 80%, while, for of aluminum saturation (M%), in 87% of the samples the values were 0.

As for the contents of organic matter (OM), 60% of the soils presented contents above 2,5% with high and low levels of potassium and phosphorus, respectively.

When the levels of potential acidity increase, consequently, there is a reduction in the availability of the main nutrients, micronutrients and the Ca:K ratio. On the other hand, when there is an increase in pH levels, there is a greater availability of nutrients and a reduction in potential acidity and aluminum levels.

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