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Multivariate Analysis of Physical and Chemical Soil Attributes Under Forage Palm Cultivation and Agriculture Reuse in the Semiarid Region

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Abstract

The use of treated effluents (UTE) for irrigation has grown considerably in recent years, especially in arid and semi-arid regions. The objective of this research was to evaluate the effect of soil fertility under cultivation with forage cactus intercropped with different legumes. The experiment was conducted over a period of two years in a research unit that uses irrigation with reuse water (RW) in consortia of cactus species with wood and forage legumes. The soil layers were analyzed in the layers of 0-10 and 10-20 cm in three seasons: T0: without reuse water (RW); T1: dry season + reuse water (RW); T2: wet season + reuse water (RW) under cultivation of three palm varieties or *cochineal cactus* (mexican elephant ear palm, small palm and baiana). The soil attributes evaluated were granulometry, soil density, pH, salinity, sodicity, macronutrients, organic matter, Mineral N and total organic carbon stock (O.C.S). The plants were periodically irrigated with domestic effluent treated with constant irrigation 2 L h^{-1}. The data were subjected to multivariate statistical analysis, using correlation matrix, cluster analysis, and factorial analysis considering the factors as principal components. According to the factorial analysis, Factor 1 (F1) and Factor 2 (F2)—F1 consisting of Sand, Ca^{2+}, pHs, stock of. K and base saturation (V), and F2 consisting of Soil Organic Matter (SOM), stock of. Mg, CEC, stock of Ca^{2+}, clay and soil density—were essential to differentiate the environments. The cluster analysis formed four groups. The structural groups showed greater similarity, denoting the relationship between source material and land use, followed by the chemical groups pHs, Ac. Pot., V^+, CEC, Na^+, stock of Na^+, PST, and Ds; the structural weighted total porosity, stock of P.; Ksoil, stock of K, and Mg, SB, Te, stock of . Mg, and finally stock of Total, stock of Nitrog, Nit. Inorg.; SOM, TOC, Ca^{2+} and Tp of soil. This is a local peculiarity due to the climatic pattern of the Brazilian semiarid region in use of domestic sewage treated in agriculture as a forage index and as a social factor. The multivariate statistical analysis through principal component analysis and clustering made it possible to form groups according to soil attributes, which can help in decision making regarding soil fertility and fertilization management in this region with agricultural reuse application mainly in semiarid regions of Brazil.

Keywords: treated domestic effluent, soil chemical attributes, forage palm, cochineal cactus

1. Introduction

1.1 Introduce the Problem

The reuse of water for irrigation purposes is a viable alternative for the supply of water needs and largely plant nutrition, functioning as agricultural fertigation, being widely studied and recommended by many researchers

(Gheyi et al., 2012; Medeiros et al., 2019). Reuse can provide sufficient flexibility to meet short-term demands, as well as ensure increased security in long-term supply (Mancuso et al., 2021).

(1) Why is this problem important?

Due to the scarcity of water that affects several regions of Brazil, associated with water quality problems, the reuse of water becomes a potential alternative for the rationalization of this natural asset, including agricultural irrigation, which represents approximately 70% of water consumption in the world.

The application of treated domestic effluents (TDE) in production of forage palm or *cochineal cactus* (palm for bovine) can become a technological and viable alternative for irrigation mainly in semiarid regions. The production of crops with treated domestic effluents has been shown to be a socially, economically and environmentally sustentable alterantive, because it brings great supply of nutrients, mainly nitrogen and phosphorus. These two elements are considered to be of high demand in the cultivation of palm or *cochineal cactus*. Therefore, the use of treated domestic sewage is similar to the use of a nutrient solution. This fact, associated with the leaching power (factor to express the loss of nutrients from the arable part of the soil to deeper parts) of nutrients in the soil, are important factors to consider in the split application of fertilizers for the crop under irrigation (Ferreira et al., 2021).

(2) How does the study relate to previous work in the area? If other aspects of this study have been reported previously, how does this report differ from, and build on, the earlier report?

Other studies were reported based on research on soil chemical composition in soil with agricultural reuse. The application of treated domestic effluents (TDE) in production of forage palm or *cochineal cactus* can become a technological and viable alternative applied to the soil mainly in semiarid regions. The production of crops with treated domestic effluents has been shown to be a socially sustainable alternative, economic and environmental, because in its constitution it brings great supply of nutrients, mainly nitrogen and phosphorus. These two elements are considered to be of high demand in the cultivation of palm or *cochineal cactus*. Therefore, the use of treated domestic sewage is similar to the use of a nutrient solution. This fact, associated with the leaching power of nutrients in the soil, are important factors to consider in the split application of fertilizers for the crop under irrigation (Ferreira et al., 2021).

The forage cactus stands out as an important forage resource adapted to the edaphoclimatic conditions of this region of low fertility and low water storage capacity in the aerial part, enduring prolonged periods of drought due to its physiological properties, characterized by the acid metabolism of crassulaceans (AMC), which gives it greater efficiency in the use of water (Silva et al., 2020). The palm varieties used were: Mexican Elephant Ear Palm (*Opuntia stricta* Haw), palm baiana, Maid's Hand or Ipa Sertânea (*Nopalea cochenillifera* Salm Dyck) and small palm or Sweet (*Nopalea cochenillifera* Salm Dyck) (Galvão Junior et al., 2014).

(3) What are the primary and secondary hypotheses and objectives of the study, and what, if any, are the links to theory?

In addition to the type of association, soil fertility management is also a determining factor in crop productivity, especially in the soils of arid and semi-arid regions that, in general, have low levels of organic matter. Considering that the extraction of nutrients by the *cochineal cactus* is high (Dubeux Júnior & Santos, 2005) and that its cladodes are harvested in the field and, normally supplied chopped to the animals in the trough, the non-replacement of these nutrients tends to decrease the productivity of the palm or *cochineal cactus* grove in a system of continuous use, due to the high export or loss of nutrients through the process of leaching or erosion (Ramos et al., 2015).

The study of soil attributes over time makes it possible to quantify the magnitude and duration of changes caused by different management systems, and even by the addition of treated domestic sewage to the soil. Because they are sensitive to the study of the chemical and physical composition of the soil, these attributes are important to establish whether there has been degradation or improvement in soil quality in relation to a given management system (Reichert et al., 2009).

The hypothesis of this study is to test the empirical veracity based on the assumption of an inverse relationship between the use of soil without agricultural reuse and good quality soil with adequate application of agricultural reuse in the dry period and with other adverse conditions such as in the rainy season.

(4) How do the hypotheses and research design relate to one another?

The benefits of water reuse in agriculture are related to environmental, economic and health issues. The alternative of using treated domestic sewage to irrigate crops has increased significantly in the last two decades due to the scarcity of water for irrigation, improvement of treatment techniques and agricultural use, the high cost of fertilizers and sewage treatment techniques before releasing them into water bodies (Santos Júnior et al., 2015). Other factors that contributed to the use of this alternative were the socio-cultural acceptance of the practice of re-using sewage in agriculture and recognition of its importance by water resource management bodies (Medeiros et al., 2019).

(5) What are the theoretical and practical implications of the study?

The planned reuse of water is an internationally established practice on all continents and has been widely used, in a safe and controlled way, in several countries, including to increase the supply of drinking water, as in semi-arid regions of Brazil (Oliveira et al., 2012). In Israel, wastewater reuse is a national priority (Varallo et al., 2012). In Europe, treated wastewater is used in irrigated agriculture, among several other non-potable uses, in about seven hundred projects, mainly in southern European countries, such as France, Greece, Italy, Portugal and Spain (Monte et al., 2010). In the United States, it's use is practiced on a large scale and tends to grow at an estimated rate of 15% per year. In Australia, the National Water Reuse Program has advanced in the proper consolidation of reuse as a water conservation practice.

1.2 Explore Importance of the Problem

Multivariate statistics can be used when there is evidence of dependence between some variables, as studied per Mota et al. (2014), verified through multivariate analysis that the degree of flocculation was the main factor influencing the results found for penetration resistance and that the contents of organic carbon have a high correlation with the density of the soil. However, this observation was not established using univariate analysis in this study. The authors recommend the use of both techniques simultaneously, in which multivariate analysis can help studies in soil science as a tool (Weirich Neto et al., 2006).

1.3 Describe Relevant Scholarship

The relationship between soil and vegetation (palm + consortium), are currently being evaluated through multivariate analysis (Silva et al., 2017). Even so, univariate or multivariate statistics are the main alternative for data processing in studies carried out in soil science or soil management and conservation (Trevisan et al., 2013) and even in the study of soil fertility under cultivation of forage species, legumes and also forest species. However, multiple variables are analyzed in these field of study, in which, generally, they present some degree of correlation with each other. In this way, the use of multivariate analysis can make it difficult to interpret some results if there is no adequate planning of the statistical data (Silva et al., 2021), causing information to be lost or suppressed in the researcher's database (Freitas et al., 2014).

1.4 State Hypotheses and Their Correspondence to Research Design

The hypothesis of this study is to test whether there is an inverse relationship between the use of soil without agricultural reuse and good quality soil with adequate application of agricultural reuse in the dry and rainy season. Therefore, the present study was designed, with the objective of evaluating soil fertility and nutrient balance through the technique of multivariate analysis of the experimental area in soil with the objective of evaluating soil fertility and nutrient balance through the technique of multivariate analysis of the experimental area in soil (giant palm, small palm and baiana) intercropped with native leguminous species and exotics adapted using reuse water for logging purposes and forage, as a form of empirical modeling to understand the supply of nutrients to the soil or nutrient cycling, and their interaction effects on the soil-effluent-nutrient system.

2. Method

The experiment was carried out under field conditions from November/2019 to December/2021, where this agricultural reuse research/treatment unit was implemented in the Municipality of Fernandes-RN. The geographic coordinates According to the Köppen-Geiger classification are: latitude 6º22′45″ (S) and longitude of 37º10′60″ (W) of Greenwich, at an altitude of 131 m above sea level, distant 293 km of the capital Rio Grandeense. According to the Köppen classification, the climate of the region is of the type BSh (rains in summer), with a rainy season from April to June.

As demonstrated in Figure 1, geographically, the municipality of São Fernando-RN is located between the rivers Seridó, which rises in Serra dos Cariris and Piranhas Açu, which bathes a large part of its rural area. The predominant vegetation in the municipality is the Hypoxerophilous Caatinga, or Shrubby Caatinga. This plant formation covers the entire central-southern portion of the state.

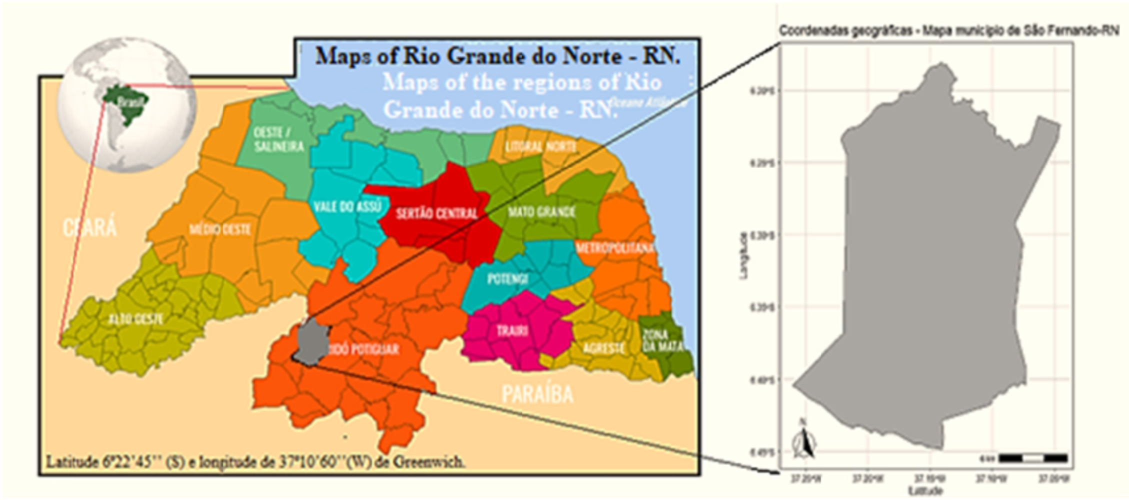

Figure 1. Geographic location of the study area referring to the application of treated domestic effluent located in the municipality of São Fernandes-RN

2.1 Plants Irrigation Systems

The agricultural reuse treatment unit consisted of some irrigation components such as: pump motor, sand filter, hydrometer and irrigation system derivation lines for the distribution of treated domestic effluent in the main and secondary plots (Figure 2).

Figure 2. Study area location (experiment) + irrigation system components operating with treated agricultural reuse

For the implementation of this agricultural reuse treatment unit for later study of the soil composition (Soil fertility), consisted of a research area (Research Unit) of 1.0 ha cultivated with three varieties of forage palms intercropped with native and exotic leguminous species adapted to the semiarid conditions of the region (Figure 2).

The palm varieties implanted or *cochineal cactus* in this to study soil fertility comprised the three varieties of palm tree or *cochineal cactus* resistant to Carmine Cochineal, like the sweet little palm (*Nopalea cochenillifera* Salm-Dick), Mexican elephant ear palm (*Opuntia stricta* (L.) Mill) and the variety of sweet palm from baiana (*Nopalea* sp.), that at the time, treatments were irrigated with four volumes or water depths: 0, 1, 2 and 3 L/week/plant. The consortium of forage palms or *cochineal cactus* were made with the leguminous species of sabiá lumber aptitude (*Mimosa caesalpiniifolia*) and algaroba (*Prosopis juliflora*) as well as legumes with forage aptitude such as gliricidia (*Gliricidia sepium*) for the formation of protein banks.

The experimental design referring to the study of soil composition specifically comprised the use of the arrangement or design in randomized blocks (DRB), with factorial scheme 3 × 2 × 3, which statistically corresponds to the three evaluation seasons (season 1—dry and without agricultural reuse application, season 2—dry and with application of agricultural reuse and finally, season 3—wet and with agricultural reuse application) and at two different depths of soil sampling to study soil composition, using the three varieties of palm or *cochineal cactus* in the main plots and, in the subplots or secondary plots, the leguminous species intercropped, with four replications. Soil sampling was carried out in two periods (dry and rainy season), those collected from soils in the rainy months (Winter) comprises the months from February to May, and in the dry period (summer)—July to November.

After collecting the samples in the field, they were processed, dried, identified and stored for subsequent physical-chemical analyses. The annual physicochemical determinations of the soils of the plots were necessary to evaluate the evolution of the soil quality and the entire nutrient balance of the water-soil-plant system after the implantation of forage cactus × legumes intercropping.

Before the implementation of the experiment and at each seasonal period (dry and wet) 24 soil samples were collected at two different depths (0-10 and 10-20 cm) for characterization or determination of physical characteristics (clay dispersed in water—CDW, density of soil—Ds, Soil texture and mineralogy) as well as chemical analyzes (pH, CEes, N—total, K^+ , Na^+, Ca^{2+}, Mg^{2+}, organic matter—OM, sodium adsorption ratio—SAR, exchangeable sodium percentage—ESP) according to methodologies compiled from the EMBRAPA (2019). Potential acidity or soil acidity was obtained by extraction with a buffered solution of calcium acetate pH 7.0. The procedure for determining the levels of Ca^{2+} the principle of extraction with solution was used KCl and complexiometric determination in the presence of eriochrome and murexide or calcon indicators, where at the end, titration is carried out by recording the volume of EDTA spent, which corresponds to the existing calcium. For the quantification of the Ca^{2+} + Mg^{2+} of the soil was made by adding 4.0 ml of the cap cocktail + 2 eriochrome indicator drops black and holder, immediately, with the solution of EDTA 0.0125 N, until the color changes from purplish-red to pure blue or greenish (with this titration are determined jointly (Ca^{2+} and Mg^{2+}).

For quantification of clay dispersed in water (CDW) pipette method was used (25 mL) using the extractor NaOH—10 mL—then passed 16 h in Wagner-type rotary shaker 50 rpm for then perform the calculations individually for each soil according to Lei for Stokes, aliquots of the clay suspension were pipetted.

The method of determining the textural analysis of the soil comprises placing 20 g of soil in a container of 200 mL. Add 100 ml of water + 10 mL of normal sodium hydroxide solution as a dispersing agent. Then, place in a Wagner-type rotary shaker at 50 rpm per 16 h, and then on the following day carry out the separation procedures by washing with distilled water in a sieve of 2 mm with the aid of a funnel. After filling the beakers with each sample, shake and wait 8 hours, then collect an aliquot of 25 mL of each sample to place in the crucible. Then take it to the oven for 24 hours to then weigh the crucible with clay and then carry out the weight difference in the crucibles without the material, this method takes the clay content of the soil. For obtain the sand fractions, at the time of washing each sample, each sample washed and completed in the beaker of 1000 mL, one part would be used to determine the clay fraction and the other part, the sand fraction separated and placed in petri dishes, where each dish with sand, 48 h must be spent in the oven and then the plates with and without sand must be weighed.

The alkalinity and salinity of the samples of soil or aqueous extract of the soil were determined by the analytical equipment pHgameters and benchtop conductivity meter, respectively. The contents of K^+ and Na^+ of the soil were determined at the analytical center of the National Institute of Semiarid—INSA, specifically in the laboratory of analytical chemistry through the use of the flame photometer.

The nutrient stores Ca^{2+}, Mg^{2+}, K^+ and P, at each depth, were calculated according to the Ellert and Bettany (1995) equation: EE = CE × Ds × E × 10, where EE means element stock (kg ha^{-1}); EC is the element content in the soil (mg kg^{-1}); Sd the density of the soil (Mg m^{-3}); and the layer thickness (m). In order to standardize the soil mass for the calculation was considered as the value of Sd the average between murundu and flat area.

2.2 Statistical Analysis

The statistical treatment was performed by analysis of variance, and the means of the qualitative data were compared by Tukey's test at 5% probability. Furthermore, Pearson's correlation and principal component analysis figures were performed, and the graph was made using the Corrplot, Ggplot and Ggcorrplot statistical package (Wei & Simko, 2017) of the software R (R Core Team, 2020).

3. Results and Discussion

The matrix correlation of the soil's attributes was evaluated in the 0-10 cm depth layers is presented in Figure 3. Strong positive correlation ($p < 0.001$) in the layer of 0-10 cm was found between PST × stock of Na^+ ($r = 0.98$), CE and stock of Na^+ ($r = 0.97$), CE and Na^+ ($r = 0.97$), CTC effective and stock of Mg^{2+} ($r = 0.91$), SB and Mg^{2+} ($r = 0.93$) and COT × MOS ($r = 0.97$). Significant strong negative correlation at the level of 1% ($p < 0.01$) also occurred between Ac. Pot × V% ($r = 0.90$), sand × silt ($r = 0.93$) and weak negative correlation of clay × stock of K ($r = 0.54$). On the other hand, weak positive correlation was found between K^+ × V ($r = -0.56$; $p < 0.001$), stock of K × V% ($r = -0.56$; $p < 0.01$), pHs × V% ($r = -0.62$; $p < 0.01$) and clay × Tp ($r = 0.46$; $p < 0.01$).

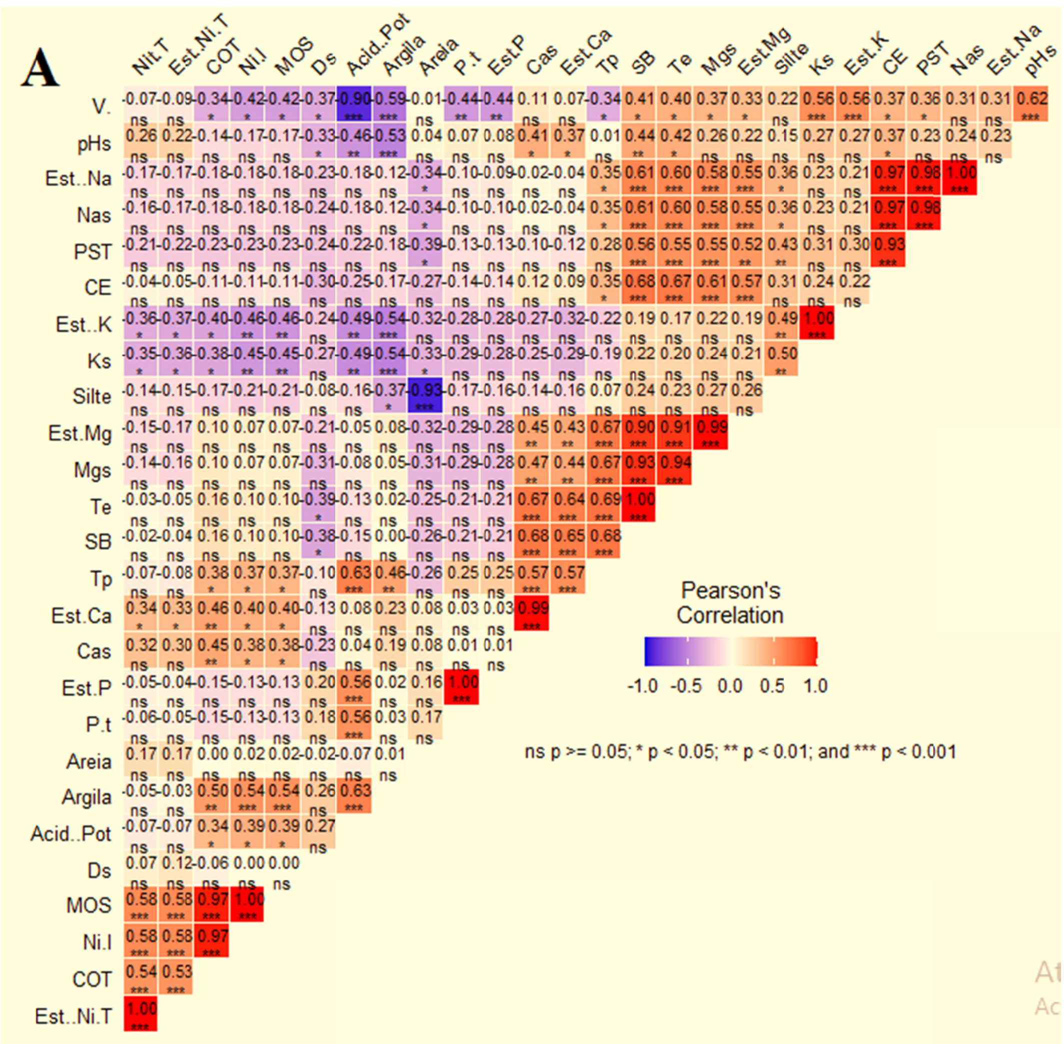

Figure 3. Pearson's Correlation Coefficients ("r") referring to the main physical and chemical characteristics of the soil evaluated at two different depths of 0-10 cm (A) under cultivation of three varieties of forage palms or *cochineal cactus* intercropped with native and exotic legumes in soil with treated domestic agricultural reuse (TDA), municipality of São Fernando-RN

3.1 Intervention or Manipulation Fidelity

Making discriminatory reference in other circumstances to soil conditions or soil fertility at the depth of 10-20 cm, the correlation matrix of the attributes evaluated in the layers of 10-20 cm of depths is shown in Figure 4. Strong positive correlation ($p < 0.001$) in the layer of 10-20 cm was found between COT × MOS (r = 0.97), Mg^{2+} × stock of Mg^{2+} (r = 1.00), Nit. Inorg. × MOS (r = 1.00), Ca^{2+} × stock of Ca^{2+}, P total of the soil × stock of P available on the ground (r = 1.00), CE with stock of Ca^{2+}, Ca^{2+} and CTC soil potential (r = 0.65), SB × stock of Mg^{2+} (0.89), CTC effective and stock of Mg^{2+} (r = 0.89) and SB and Mg^{2+} (r = 0.89). Significant strong negative correlation at 1% level ($p < 0.01$) also occurred between sand × Silt (r = -0.93) and Ac. Pot × V% (r = -0.81). However, one can also perceive a weak positive correlation of Sand × stock of Mg^{2+} (r = 0.57), V% × COT (r = 0.48) and V% × MOS (r = 0.48). On the other hand, Weak negative correlation was found between Silt × stock of K^{+}, stock of. Mg^{2+}, CTC effective soil ($p < 0.001$), and finally, the Sd × Silt (r = 0.35). The attributes that had the highest number of correlations were more important in the composition of the factor axes, evidenced how the preliminary analysis of the correlation matrix can help in the removal or addition of variables (Figueiredo Filho, 2010).

3.6 Baseline Data

Be sure that baseline demographic and/or clinical characteristics of each group are provided.

3.6.1 Statistics and Data Analysis

In studies reporting the results of experimental manipulations or interventions, clarify whether the analysis was

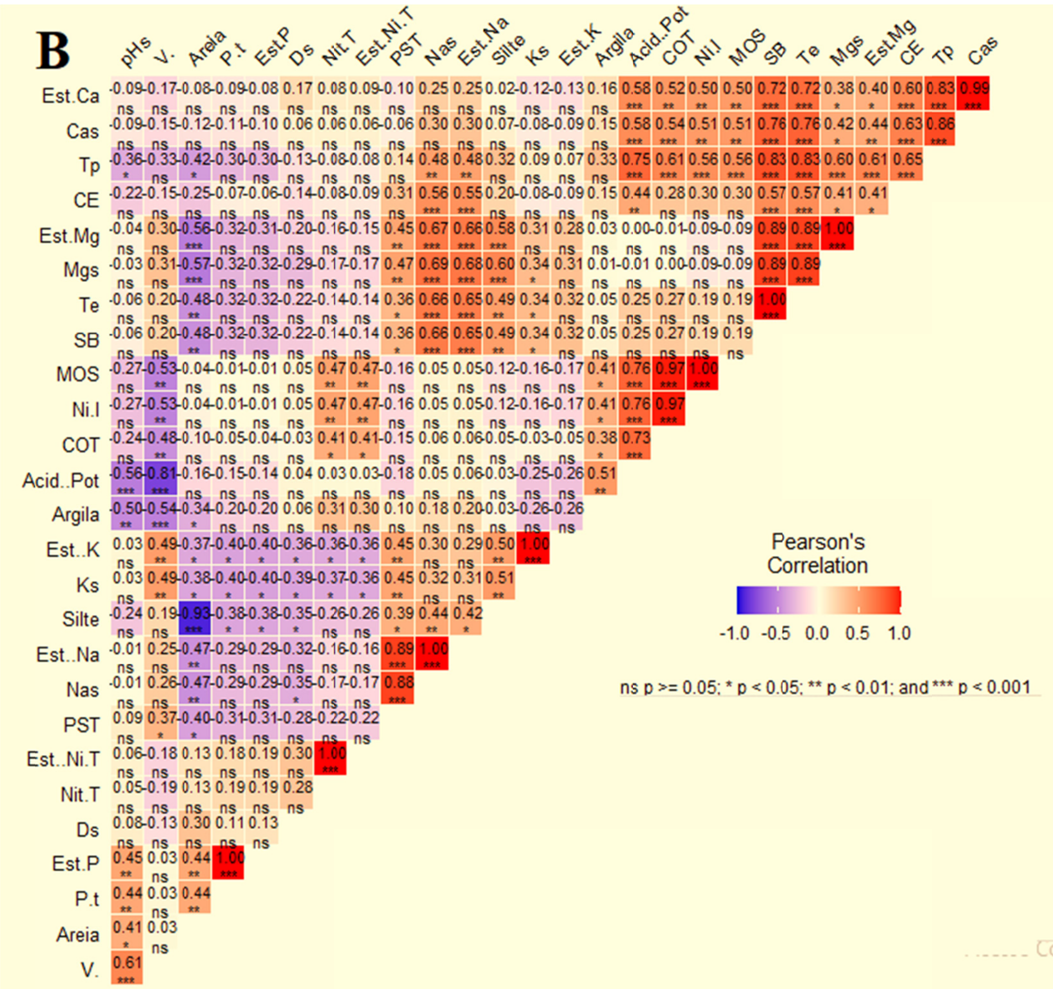

Figure 4. Pearson's Correlation Coefficients ("r") referring to the main physical and chemical characteristics of the soil evaluated at two different depths of 10-20 cm (B) under cultivation of three varieties of forage palms or *cochineal cactus* intercropped with native and exotic legumes in soil with treated domestic agricultural reuse (TDA), municipality of São Fernando-RN

Table 6 presents the factors extracted from the 28 variables studied referring to the study of the chemical composition of the soil under agricultural reuse application (pHs, CE, Acid. soil potential, Nit. total (Nt), nit. Inorganic (Ni), total phosphorus (P), soil potassium (K^+), exchangeable sodium (Na^+), exchangeable cation (Ca^{2+}), Magnesium (Mg^{2+}), Total nitrogen stock (stock of Nit. T), Potassium stock (stock of K^+), phosphorus stock (stock of P), calcium stock (stock of Ca^{2+}), magnesium stock (stock of. Mg^{2+}), Sodium stock (stock of Na^+), org carbon total (COT), Soil organic matter (SOM), soil density (Ds), CEC effective soil (CEC), base saturation (V%), sand contents, silt and clay), and the accumulated proportion was from Factor 1 (F1) to the Factor (F7) explaining about 88.01% of the total variability of the results obtained, losing only around 4.69% of the data explanation. With 4 factors, approximately 70.38% of the data variation is explained. Second Fávero and Belfiore (2017), usually the number of elements that account for 70% or more of the total variance dimension is used.

The first factor showed a greater number of positive and high correlations with most of the analyzed soil attributes or response variables (physical and chemical soil attributes). The F1 allowed estimating the influence of expressive variables of the treated domestic effluent, that have positive factor loadings, revealing that most of the causes of variation of F1 with 27.39%, occurs by the chemical interference character variables of the application of the effluent to the soil, such as: Ca^{2+}, Mg^{2+}, stock of Ca^{2+}, stock of Mg^{2+}, Ds and Te. F2 explained (49.64%), of the variation of the data, and was represented by: Nit. Soil inorganic, COT and SOM. This relationship can be attributed to the organic matter that contributes to the increase in the cation exchange capacity and areas with a greater contribution of litter, there is an intense cycling of soil organic matter, with increased mineralization and increased release of nitrogen in the soil (Machado et al., 2018). In F3 were the variables: total soil phosphorus and stock of P in soil, which, therefore, presents positive factor loadings in the order of 60.41%.

F4 stand out the variables: CE, Na^+, stock of Na^+ and PST with (70.38%). Additionally, the leaching of bases favors the relative increase in the concentration of ions H^+ and Al^{3+} in the soil solution (Sousa et al., 2007). As for F5, the variable that stood out was: Acid. Pot, V% and Clay, representing a percentage value in the order of 78.19%.

How many at the other factors (F6 and F7) these were more expressive in relation to the study of the chemical composition of the soil on the different interactions present in the system soil-effluent-plant-atmosphere, with lower factor loading values, for the attributes Sand and Silt, vs Nit.T and stock of Ni.T with 83.32%, versus 88.01%, respectively, being strongly influenced by the factors (F4 and F5).

Table 1. Factor axes extracted from soil samples to study physical and chemical attributes under the effect of domestic sewage application from the experimental station in INSA, located in the city of São Fernando-RN, regarding the respective factor loadings, eigenvalues, total and accumulated variance

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
pHs	0.22	0.16	-0.34	0.18	0.65	-0.19	0.24
CE	0.26	-0.04	0.00	0.92	0.06	0.01	0.01
Acid. Pot	0.12	-0.54	-0.20	-0.09	-0.71	0.07	-0.26
Nit.T	-0.06	-0.37	-0.03	-0.05	0.02	-0.08	0.87
Ni.I	0.13	-0.92	0.04	-0.04	-0.19	-0.05	0.24
P t	-0.10	0.03	-0.95	-0.06	-0.10	-0.12	0.02
K^+	0.01	0.03	0.25	0.08	0.67	0.45	-0.39
Na^+	0.12	0.06	0.03	0.98	0.03	0.09	-0.03
Ca^{2+}	0.84	-0.35	-0.08	-0.06	-0.02	-0.19	0.10
Mg^{2+}	0.76	0.11	0.24	0.36	0.06	0.27	-0.09
Stock of Ni.T	-0.02	-0.33	-0.10	-0.07	0.02	-0.04	0.88
Stock of K	0.07	0.01	0.21	-0.05	0.64	0.44	-0.37
Stock of.P	-0.08	0.04	-0.94	-0.06	-0.02	-0.13	0.10
Stock of Ca	0.77	-0.28	-0.17	-0.16	-0.01	-0.09	0.13
Stock of.Mg	0.79	0.16	0.12	0.07	0.10	0.34	-0.01
Stock of Na	0.19	0.06	0.04	0.95	0.05	0.13	-0.04
COT	0.19	-0.93	0.05	-0.06	-0.11	0.00	0.18
MOS	0.13	-0.92	0.04	-0.04	-0.20	-0.05	0.24
Ds	0.87	-0.11	0.13	0.39	0.14	0.14	-0.06
Te	0.87	-0.11	0.14	0.39	0.12	0.13	-0.07
V%	0.19	0.41	0.16	0.19	0.79	-0.04	0.09
PST	0.04	0.09	0.05	0.96	0.09	0.15	-0.06
Ds	-0.13	0.21	-0.07	-0.24	-0.43	0.03	0.35
Sand	-0.18	0.03	-0.18	-0.20	0.12	-0.89	0.04
Silt	0.15	0.09	0.09	0.20	0.15	0.89	-0.06
Clay	0.07	-0.33	0.24	-0.01	-0.70	-0.01	0.06
Eigenvalues	7.39	6.01	2.91	2.69	2.11	1.38	1.27
% variance	27.39	22.25	10.78	9.96	7.82	5.12	4.69
Cumulative variance%	27.39	49.64	60.41	70.38	78.19	83.32	88.01

Second Letelier-Gordo et al. (2020), a high content of sodium in the wastewater is an inhibitor for the effectiveness of the treatment process, however, this inhibitory effect decreases when there is an increase in organic matter in the effluent. According to Lyn et al. (2020), the lower the amount of organic matter present in the effluent, the lower the rate of DQO.

This probably occurred because it is inside the soil that the various interactions between the soil and the active microorganisms occur (higher enzymatic activity of microbial biomass) of the soil, thus creating a favorable microclimate for the development of palm varieties or *cochineal cactus* and of legumes with aptitude for wood manufacturing and others with the purpose of forage indices, to improve thus, the forage support of the animals mainly in semi-arid regions.

In the correlation circle on the effect of treated agricultural reuse on soil fertility, for F1, we can see that strong correlation between variables, such as: K^+ and V% positively, showing that there was greater variation in soil fertility under the effect of the application of agricultural reuse opposing with negative correlations for the variable Clay, SOM, Sd and Potential acidity of the soil. Dor F2, BS, Ca^{2+}, stock of Ca^{2+}, Tp and Mg^{2+} have greater positive variation evaluated at a depth of 10-20 cm in the dry season for the Mexican elephant ear palm variety or *cochineal cactus*, as can be seen in Figure 5.

Based on this figure, we can clearly see that the varieties of palm or *cochineal cactus*, Mexican elephant ear and miúda were the ones that most positively influenced soil fertility and in the depth of 0-10 and 10-20 cm, respectively.

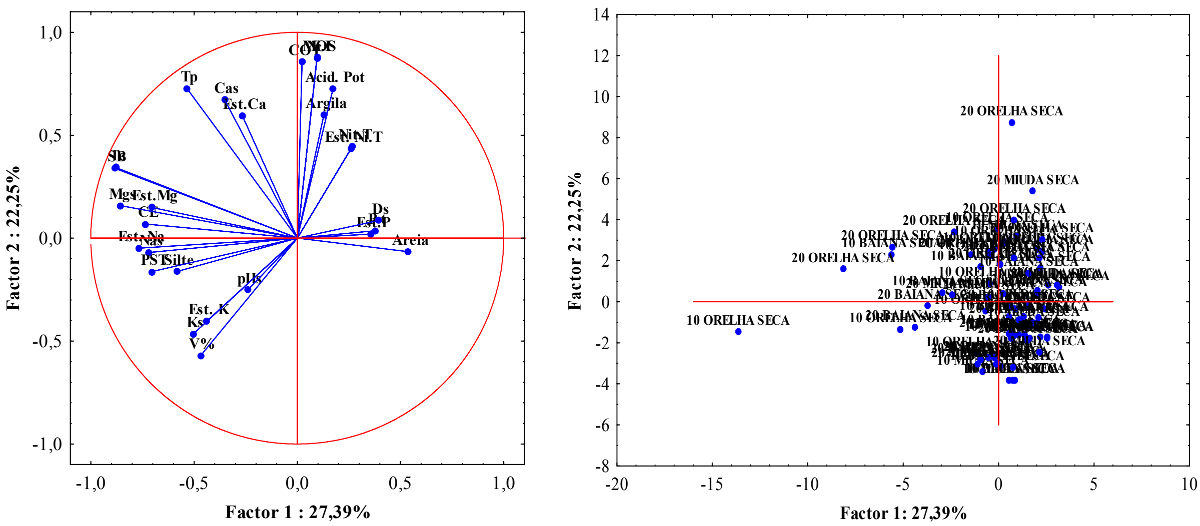

Figure 5. Distribution of the variable cloud, in the correlation circle (A) and distribution of the point cloud representing the varieties of palms or *cochineal cactus* and times of application of agricultural reuse related to the factors 1 and 2 (B), located in the municipality of São Fernando-RN

To the F3 and F4, the variables pHs, stock of K^+, contentes of K^+ and V% of the soil had a greater variation to the detriment of the elephant ear palm varieties or *cochineal cactus* than the other varieties under study (baiana and small palm or *cochineal cactus*), and on the other hand, the density of the soil, Potential acidity of the soil, clay and organic matter contents. In general, the study of industrial wastewater, animals or the municipal sector specifically, have in their constitution high concentrations of phosphorus, potassium and nitrogen (Figure 6).

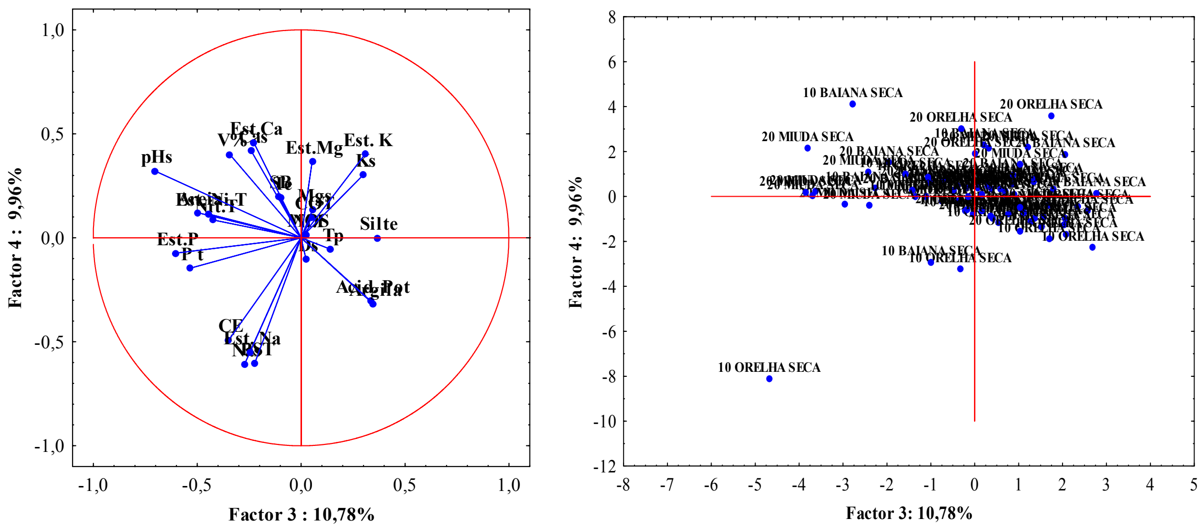

Figure 6. Distribution of the variable cloud, in the correlation circle (A) and distribution of the cloud of points representing the varieties of palms or *cochineal cactus* and times of application of agricultural reuse related to the factors 3 and 4 (B), located in the municipality of São Fernando-RN

Long-term irrigation with this type of treated domestic effluent has negative effects on the structural stability of the soil, even so, the supply of water and nutrients, such as potassium, phosphorus, nitrogen and exchangeable cations may play an essential role in soil fertility, serving to maintain the balance of biogeochemical cycles, nutrient cycling via the soil-effluent-plant-atmosphere system, greater control of soil pH favoring greater availability of nutrients to plants through irrigation of agricultural reuse as a form of supply or water resource in semi-arid regions; with this it is understood that the agricultural reuse in the long term, with the use of effluent with high concentrations of potassium, it needs to be balanced with the risks of soil dispersion (Liang et al., 2021).

The attributes pHs, Acid. soil potential, V% and soil clay was representative for group I at a significance level of 5% probability by the cluster dissimilarity test, where in this classification group, we have the indication of young soils, unweather, eutrophic (sum of bases ≥ 50%), with low fertility due to its content of Na^+; the slight increase in CE indicating low fertility levels for this soil class (Eutrophic Regolithic Neosol) (Figure 5). Group II was distinguished from the others by encompassing only the soil density isolated by branching or clustering, and according to the study of this correlation matrix (Table 1 and Figure 7), the chemical attributes CE, Na^+, stock of of sodium (Na^+) and TSP from soil, were significant at the 1% probability level by the dissimilarity test (Soil clustering). This indicates young, poorly weathered soils, with physical limitations in terms of drainage due to intrinsic characteristics and location in the landscape (lower levels).

Group III was specifically represented by chemical attributes: total soil phosphorus (P t), Phosphorus stock in the soil (stock of P), soil potassium (K^+) and Potassium stock available, indicating with this a greater correlation of clustering of these chemical elements in the study of soil and greater availability of nutrients in the soil improving soil fertility. Group IV was clustered by the elements Mg^{2+}, sum of bases (SB), effective exchange capacity (Te) and magnesium stock (Mg^{2+}), thereby indicating higher levels of Ca^{2+} and Mg^{2+} as exchangeable cations, favoring greater dynamics of the exchange complex or soil sorption complex.

Group V was constituted by the levels of Sand and Silt, respectively. This group specifically is representative of young or shallow soils with low soil fertility and greater leaching of essential plant nutrients at the expense of soil pore size (sandy soils).

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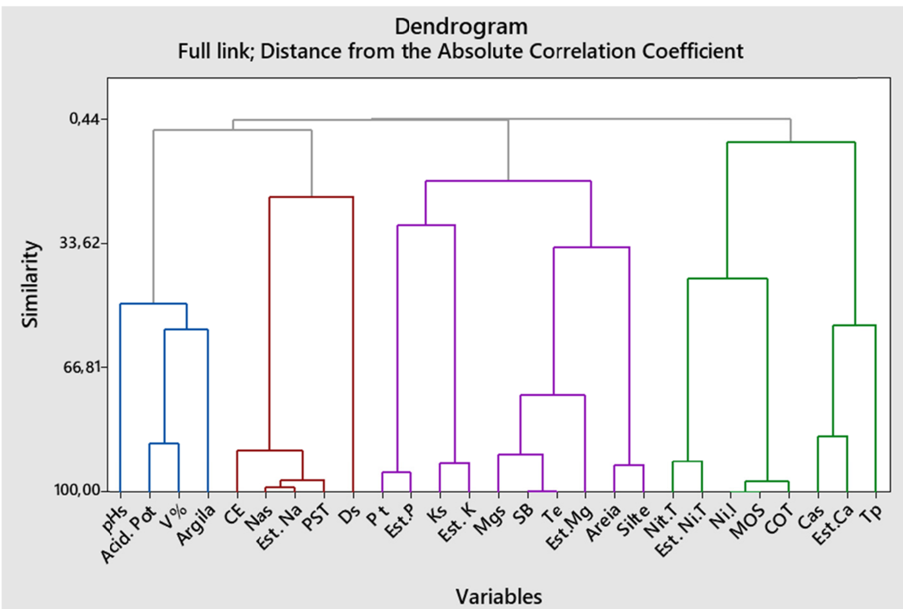

Figure 7. Dendrogram of the similaty distance matrix by the linkage-based clustering of data referring to groups soil fertility under agricultural reuse application cultivated under the conditions of three forage palm varieties or *cochineal cactus*

Group 8 was representative of the probable soil cations (Ca^{2+}) and the potential cation exchange capacity of the soil (Tp) thus indicating greater exchange of Ca^{2+} in the soil to the exchange complex, which leads to greater dissipation of cation exchange in the soil solution.

In the dendrogram generated by the cluster analysis (Figure 8), the reading is made from right to left, in which the y axis indicates the distances between the formed groups, and the × axis represents the groups joined in descending order of similarity.

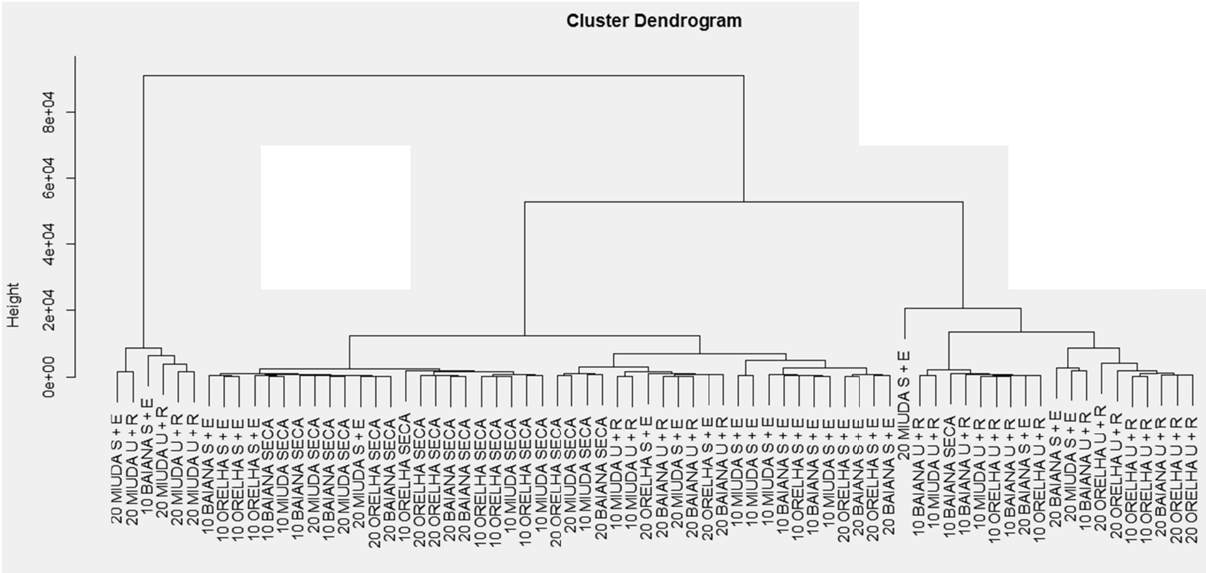

Figure 8. Dendogram of the distance matrix by the linkage-based clustering of data referring to soil fertility under agricultural reuse application cultivated under the conditions of three forage palm varieties or *cochineal cactus*

By Figure 9, it is observed that the measure of similarity between the clusters decreases and the distance increases the smaller the number of clusters. In sum, doing a broader study on the clustering of soil fertility data under cultivation of forage palms or *cochineal cactus* (elephant ear, small palm and baiana) intercropped with different types of legumes, the dendrogram and the different clusters (hierarchical groups) of soils and their interrelationships in the soil-plant-effluent system are presented considering the complete linkage method as shown in Figure 7. Through this figure, it is observed that there are well-defined clusters in the data, since the most correlated groups represent those groupings of statistically similar elements, that is, the most strongly correlated groups from a hierarchical point of view were groups 30 and 16, respectively. However, with a more detailed analysis of the dendrograms of those smaller clusters, we observed that they are poorly correlated within a hierarchical clustering set.

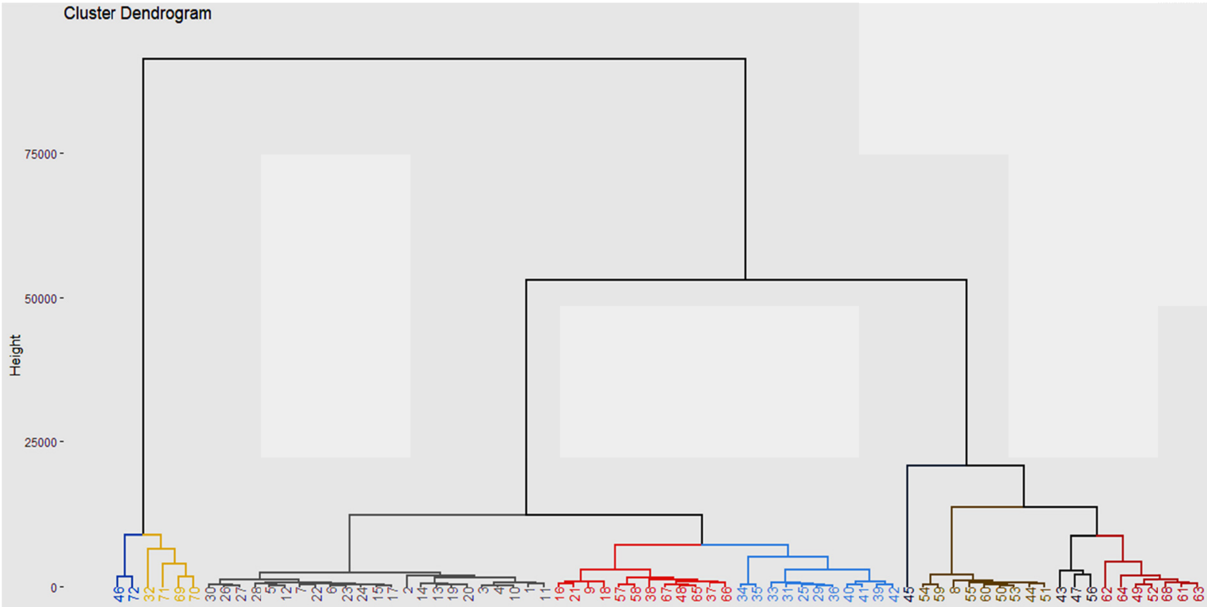

Figure 9. Clusterizations of the distance matrix by the linkage-based clustering of data referring to soil fertility under agricultural reuse application cultivated under the conditions of three forage palm varieties or *cochineal cactus*

On the one hand, the methods show that there are well-defined hierarchical groupings in the soil fertility data, strongly correlated with different application times (time of the year—dry and rainy) of agricultural reuse as well as, on the other hand, each method identified a different type of pattern from the other analyzed methods.

To validate this interpretation of the dendrograms, the correlation was calculated between Euclidean bonding distances and the correlation units in nine hierarchical groups in the study of the relations of solutions obtained by the different clustering algorithms evaluated.

4. Conclusions

Of the twenty-eight variables analyzed, nine factors were sufficient to detect 88% of the total variation of soil chemical attributes, showing that it is possible with the use of factor analysis to reduce the number of variables studied in soil science or even in the relationship between soil management and soil conservation techniques. The factors found were related to soil organic matter content, soil organic carbon and stocks of C, P, K^+, Ca^{2+} and Mg^{2+} (factor 1), favoring the improvement of soil fertility by supplying nutrients from agricultural reuse.

Through the study of multivariate statistical analysis and analysis of principal components and their groupings, it allowed forming or suppressing several variables or groups according to soil attributes, which can help in decision making regarding soil fertility and fertilization management in this area. Region with application of agricultural reuse mainly in the Brazilian semi-arid region.

Cluster analysis proved to be a useful and suitable technique or instrument for identifying different irrigation management systems for reuse of treated domestic sewage water for agricultural use, considering its potential in soil fertility, which can be cultivated with several varieties of palm for dairy cattle or for animal feed. The analysis allowed the identification of nine groups of soil fertility for analysis and interpretation of data for recommendation and spatialization of these data on the adequate management of the dose, of the irrigation technique for agricultural reuse at the appropriate time of the year.

Soil quality for the studied palm varieties or evaluated according to the fertility methods used of the soil in relation to physical and chemical attributes, they are ordered as follows: Mexican elephant ear > small or sweet palm > Baiana palm or *cochineal cactus*.

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peer reviewers or editors, associate editors, and consulting editors of the journal in which the article is to appear. In this paragraph, also explain any special agreements concerning authorship, such as if authors contributed equally to the study. End this paragraph with thanks for personal assistance, such as in manuscript preparation.

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