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Physicochemical characteristics of the soil and its importance for fish farming

Características físico-químicas do solo e sua importância para piscicultura

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ABSTRACT

Ponds built on land are the main production units for aquatic organisms and the characteristics of the base soil of these structures influence the quality of water and the aquatic ecosystem formed for production. The objective of this study is to verify the characteristics of fish farms' soils and address their importance for fish farming. The study was based on the collection of base soils for the construction of fish ponds in the city of Dourados - MS, Brazil. Particle size, pH, organic matter (OM), effective (t) and potential cation exchange capacity (T), base saturation (V%), and aluminum saturation (m%) were evaluated. There was a significant positive correlation between pH x V% (0.77) and V% x t (0.74). There were significant negative correlations between the chemical variables pH x m% (-0.87), V% x m% (-0.88) and physical variables with clay in relation to sand (-0.91) and silt (-0.83). The correlation results corroborated the clusters formed by the PCA analysis, which indicated the existence of three groups of variables considering the first two dimensions. A negative relationship of m% x pH and V% was evident. When performing the grouping of properties according to soil parameters, three groups formed. This shows that even properties built on soils of a same pattern, such as a floodplain site, may show differences in physical, chemical, and soil organic matter parameters.

KEYWORDS: aluminum saturation; aquaculture ponds; floodplain; pH.

RESUMO

Viveiros aquícolas em terra são as principais unidades de produção de organismos aquáticos e as características do solo base dessas estruturas influenciam na qualidade de água e no ecossistema aquático formado para produção. O objetivo desse estudo foi verificar as características de solos de pisciculturas e abordar a importância do tema para a atividade. O estudo baseou-se na coleta de solos base da construção de viveiros de sete pisciculturas do município de Dourados – MS, sendo verificado a granulometria, pH, matéria orgânica (MO), capacidade de troca catiônica efetiva (t) e potencial (T), saturação por bases (V%) e saturação por alumínio (m%). Foi realizada análise descritiva dos dados, determinação dos índices de correlação e análise dos componentes principais (PCA). Verificou-se que houve correlação significativa positiva entre pH x V% (0,77) e V% x t (0,74). Correlações significativas negativas foram verificadas entre as variáveis químicas pH x m% (-0,87), V% x m% (-0,88) e as variáveis físicas com a argila em relação a areia (-0,91) e silte (-0,83). Os resultados de correlação corroboram com os clusters formados pela análise de PCA, a qual indicou a existência de três grupos de variáveis considerando as duas primeiras dimensões, onde ficou evidente a relação negativa entre m% x pH e V%. Ao realizar o agrupamento das propriedades em função dos parâmetros do solo, houve a formação de três grupos, demonstrando que mesmo propriedades construídas em solos do mesmo padrão, como locar de várzea, podem apresentar diferença nos parâmetros físicos, químicos e matéria orgânica do solo.

PALAVRAS-CHAVE: *saturação por alumínio; viveiros aquícolas; várzea; pH.*

INTRODUCTION

Aquatic organisms can be cultivated in different types of production units, such as ponds, tanks, and cages. Among them, ponds stand out and are the main production structures in world aquaculture (DUAN et al. 2020). This is also true in Brazil, where the production of freshwater fish stands out and ponds correspond to 84% of the production units of these animals (PEIXEBR 2020). They are characterized as soil structures that delimit a space in which the water used in production will be stored for a certain period (TIDWELL 2012). According to that author, due to hydraulic residence, the formation of a natural ecosystem in the water occurs and its quality will be affected by the physical, chemical, and biological factors within these production units.

Soils have different characteristics that affect the construction of nurseries and the water quality of the ecosystem that will be formed (KAMAL et al. 2018, SOUZA et al. 2021). Among soil parameters, texture, pH, cation exchange capacity, and organic matter stand out (BOYD 1995). Texture is related to the percentage of sand, silt and clay and affects the stability of slopes, the molding of the pond during construction and later infiltration, which is the main factor responsible for the loss of water in the system (ITUASSÚ & SPERA 2018).

The chemical composition of the soil must be verified because in the production of aquatic organisms in ponds, there is an interaction between water-soil-biota, similarly as what occurs in soil-plant-animal relationships in agriculture (BARUA & GHANI 2012). Cation exchange capacity indicates how much the soil is able to adsorb and release cations, such as Al^{2+}, Ca^{2+}, Mg^{2+} and K^+, and is directly related to the active fraction of the soil, which is represented by clay and organic compounds (LI et al. 2018). This causes the soil to interfere with parameters such as pH, electrical conductivity, and concentration of cations in the aquatic environment (LI et al. 2013). Soil organic matter comes mainly from plant residues and is found in greater amounts in fully or partially saturated soils, such as lowland areas (HAN & BOYD 2018, SOUZA et al. 2021). This is because the amount of oxygen in saturated soils is low, which decreases the efficiency of decomposition since it is carried out mainly by aerobic bacteria (BAXA et al. 2021). The pH in organic soils in saturated locations is usually acidic due to metabolites formed in the decomposition and leaching of cations such as Ca^{2+} and Mg^{2+} (BRADY & WEIL 2013, MENDONÇA et al. 2021). Lowland areas are widely used in fish farming and the organic matter present there may interfere with the oxygen demand in the aquatic ecosystem formed and in the development of benthic organisms and may result in less stability of slopes, as it makes the compaction process less efficient (BARUA & GHANI 2012).

The knowledge of soil characteristics provides subsidies for choosing the best location for the implementation of aquaculture activity. It also allows showing a need to carry out procedures such as liming and incorporation of oxygen in the water. Due to the importance of the soil and its influence on the aquatic ecosystem, the objective of this study is to verify the physical and chemical parameters and the amount of organic matter in fish farms' soils and discuss the importance of soil composition for fish farming.

MATERIAL AND METHODS

This study was based on soil collection from seven fish farms located in the municipality of Dourados – Mato Grosso do Sul, Brazil (Figure 1). Three samples were collected from the free edge of the ponds of each property, which were then sent for laboratory analysis to determine soil texture and chemical parameters (Figure 2). The free edge was defined as the sampling site, as it is not in direct contact with water, which allows verifying the properties of the original soil used in the construction of ponds.

Soil samples were collected in triplicate. Each triplicate sample was made up of a mixture of 5 subsamples collected in different parts of the freeboard of the ponds. The samples were dried, crushed, and sieved in a sieve with a 2-mm opening and subjected to analysis of particle size, organic matter, organic carbon, and chemical parameters.

The chemical parameters analyzed were pH ($CaCl_2$), exchangeable acidity, and verification of cation concentration (Al^{3+}, Ca^{2+}, Mg^{2+}, and K^+). Soil pH was verified using 0.01 mol L^{-1} of a $CaCl_2$ solution. Exchangeable Al^{3+}, Ca^{2+}, and Mg^{2+} were extracted with neutral KCl at 1.0 mol L^{-1} and K^+ with Mehlich-1. Based on the values obtained, the sums of exchangeable bases were calculated ($BS = Ca^{2+} + Mg^{2+} + K^+$), effective CEC ($t = Ca^{2+} + Mg^{2+} + K^+ + Al^{3+}$), potential CEC ($T = Ca^{2+} + Mg^{2+} + K^+ + H^+ + Al^{3+}$), base saturation ($V\% = (100 \times (Ca^{2+} + Mg^{2+} + K^+)/T)$), and aluminum saturation ($m\% = (100 \times Al^{3+})/t$). The analyses were performed according to methodologies described by EMBRAPA (2017).

In order to characterize the soils, a descriptive analysis of the results was performed, thus obtaining the mean value for each parameter evaluated in each fish farm and the total mean value. Particle size, pH, OM, t, V, and m data were submitted to correlation analysis and principal component analysis (PCA) in order to carry out a characterization of the related variables and properties. Statistical analyses and plotting of graphs were performed by the statistical computational system R Development Cote Team using the packages PerformanceAnalytics (CARL & PETERSON 2012), Factoextra (KASSAMBARA & MUNDT 2020), and FactoMineR (LÊ et al. 2008).

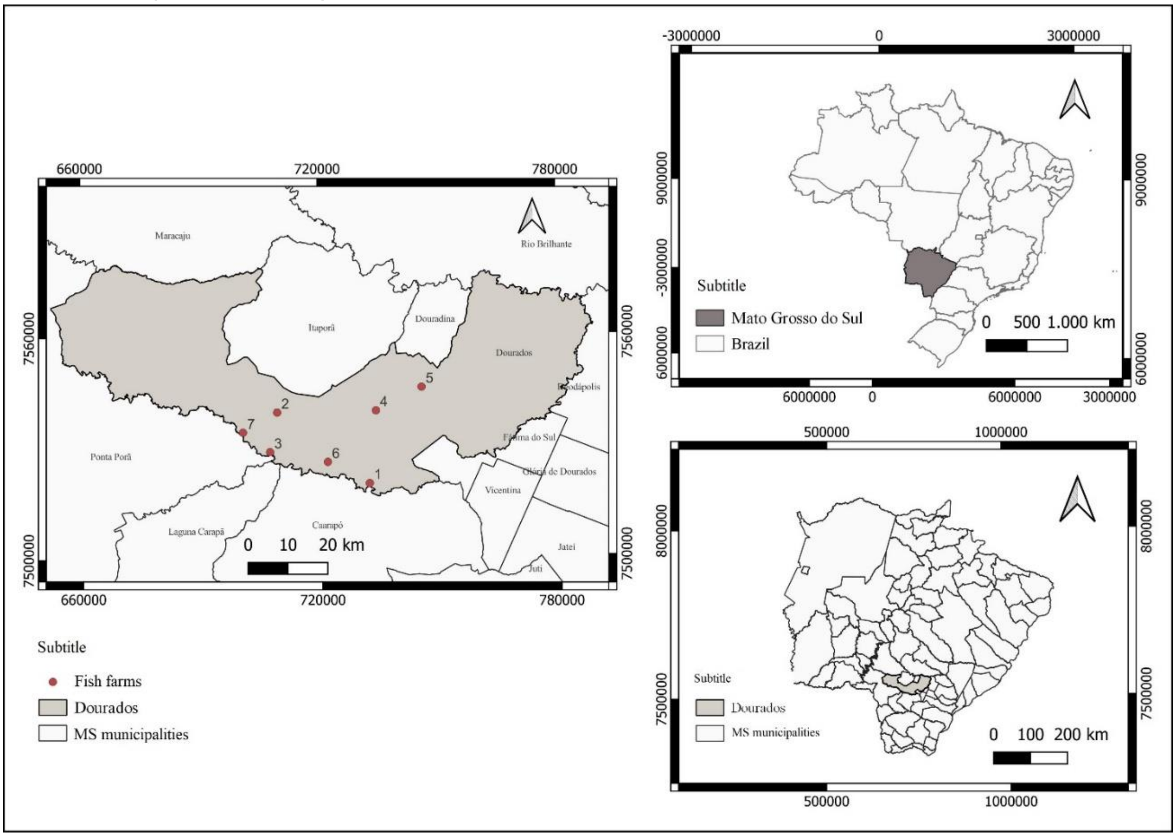

Figure 1. Location of fish farms in which soil collections were carried out.

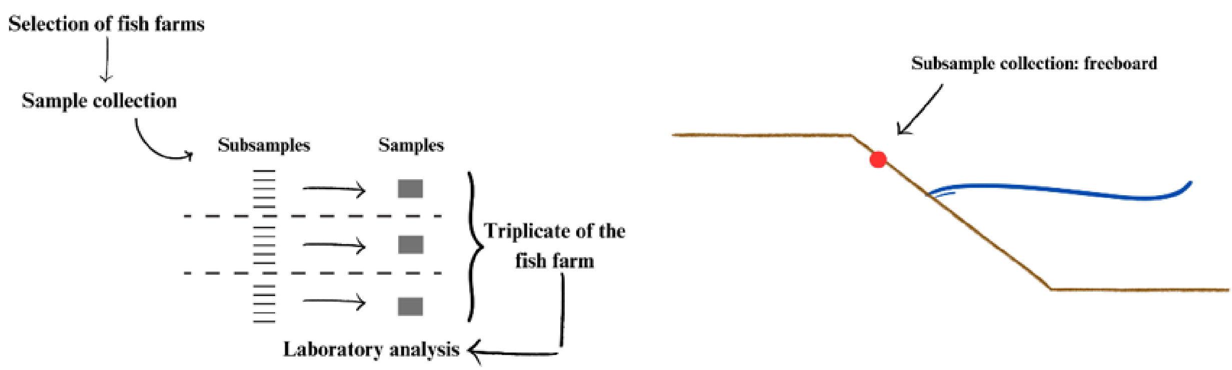

Figure 2. Collection flow chart and sampling site.

RESULTS AND DISCUSSION

The results show that the lands evaluated have acidic soil, with pH ranging from 4.0 to 5.1 (Table 1). The decrease in pH due to processes that acidify the soil may interfere with the aquatic ecosystem in ponds. A pH value lower than 5.5 reduces the activity of bacteria in the soil, which are responsible for the degradation of organic matter and nitrification (FASSBENDER 1987). This is a fundamental process in the aquatic environment in which the transformation of ammonia, toxic to organisms, into nitrate occurs.

Lands 3 and 7 had the lowest values of base saturation in the soil (V%) and had the highest aluminum saturation (m%): 8.49 and 10.30%, respectively. Base saturation indicates the percentage of non-acidic cations (Ca2+ + Mg2+ + K+) that occupy the exchange sites of soil colloids and is directly related to pH and a greater capacity of cation exchange (LI et al. 2018). BOYD (1974) verified that this index can be used to determine the amount of limestone to be applied in an aquaculture pond since, when performing liming, increasing the base saturation to 80% is enough to maintain the alkalinity and total water hardness at levels suitable for fish farming. In the evaluated lands, the base saturation ranged from 39.16 to 79.48%, indicating that it is not possible to manage water liming without considering soil characteristics.

Table 1. Chemical characteristics, particle size, and concentration of organic matter of soils of fish farms in the city of Dourados, MS, Brazil.

Fish farm	pH	t (cmol dm^{-3})	T (cmol dm^{-3})	V (%)	m (%)	OM (g dm^{-3})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Site
1	4.70	19.76	27.38	72.11	0.35	23.11	236.00	359.00	405.00	Floodplain
2	4.40	16.05	26.00	60.12	2.51	17.89	214.00	331.00	455.00	Floodplain
3	4.30	6.31	14.75	39.16	8.49	17.10	448.67	321.00	230.33	Floodplain
4	4.70	5.83	10.63	54.46	0.80	11.66	112.00	211.00	677.00	Drain
5	5.10	14.28	18.84	75.79	0.00	15.72	208.33	186.67	605.00	Drain
6	4.60	24.09	30.23	79.48	0.29	12.38	331.00	341.33	327.67	Floodplain
7	4.00	14.04	29.88	42.22	10.30	21.22	221.33	179.33	599.33	Floodplain
General mean	4.54	14.33	22.51	60.47	3.24	17.01	253.04	275.61	471.33	

t: effective CEC; T: potential CEC; V: base saturation; m: aluminum saturation.

The cation exchange capacity, represented by t and T, are important factors to be verified in a soil intended for the construction of aquaculture ponds. LI et al. (2013) evaluated different types of soils and water and showed that soils caused an increase in pH, conductivity, and concentration of main cations in the water. However, changes in water quality parameters were greater in soils that had a higher cation exchange capacity.

Thus, the greater the CEC of a soil, the greater the retention capacity and availability of cations in the water, and consequently the greater the volume of product needed at the time of liming water in the pond to reach the desired effect (SONNENHOLZNER & BOYD 2000). In the present study, the effective CEC (t) ranged from 5.83 to 24.09 cmolc dm-3 and the potential CEC (T) ranged from 10.63 to 30.23 cmolc dm-3, indicating that the soils will act in the exchange of cations differently among the evaluated fish farms.

The particle size composition of the soils showed great variation, mainly in the amount of clay, which ranged from 230.33 to 677.00 g Kg-1. The lands, except for P3, meet the minimum clay required for construction of ponds, which, according to BOYD (1995), is 30%, in order to allow for terrain shaping, slope stability, and reduction of water loss by infiltration.

There was a significant positive correlation between pH x V% (0.77) and V% x t (0.74) (Figure 3). There were significant negative correlations between the chemical variables pH x m% (-0.87), V% x m% (-0.88) and physical variables with clay in relation to sand (-0.91) and silt (-0.83).

In the soil solution, aluminum Al3+ has a strong tendency to hydrolysis, separating water molecules into H+ and OH- ions. Aluminum allow the incorporation of up to 3H+ in the solution (BRADY & WEIL 2013):

Therefore, aluminum saturation (m%) in soil colloids decreases pH and is inversely proportional to base saturation (V%).

The PCA results showed that the first three components absorb 89.1% of the PCA variance, and individually PC1, PC2, and PC3 explain 36.1%, 34.0%, and 19.0%, respectively (Table 2). Considering the first two components, pH variables, V%, and m% were more representative in axis 1, clay, silt, t and T stand out in axis 2 (Table 2).

For the variables, considering dimensions 1 and 2, there was the formation of three clusters; the first cluster formed by V%, pH and clay, the second cluster formed by m%, OM and sand, and the third cluster formed by silt, t, and T (Figure 4). The results of PCA analysis corroborate the correlation analysis. It can be verified, for example, that m% is opposite to V% and pH, and clay graphically opposes to silt and mainly sand.

Colloidal soil particles are the most reactive fraction of soil and are formed by clay (< 0.0002 mm) and small organic compounds (LI et al. 2018). Colloids are electrically charged and generally have a negative charge, consequently attracting bonds with cations. The first cluster formed in the PCA analysis shows the relationship between clay and the ability to attract cations, mainly non-acidic, which results in a higher pH. In the present study, in all properties, V% stood out in relation to m%.

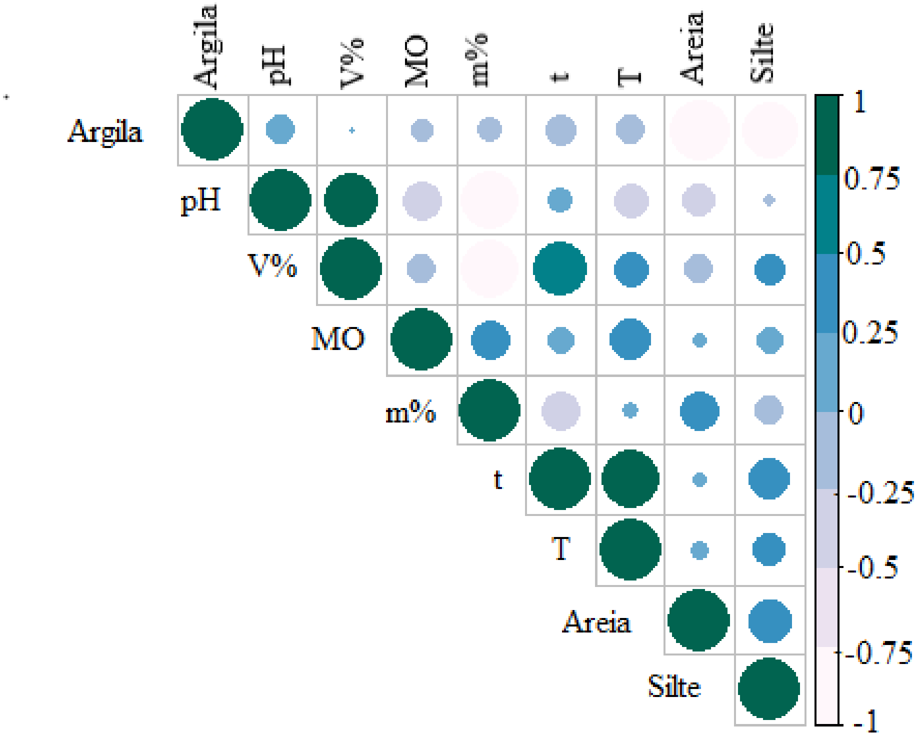

Figure 3. Heat map of Pearson's correlation coefficients between physicochemical variables and soil organic matter from fish farms in Dourados - MS, Brazil. V%: base saturation; OM: organic matter; m%: aluminum saturation; t: effective CEC; T: potential CEC.

Table 2. Pearson and Kendall correlations observed between physicochemical variables and soil organic matter and the first three ordering axes of the principal component analysis.

Variable	Axis 1	Axis 2	Axis 3
Eigenvalue	3.25	3.05	1.71
Variance (%)	36.12	33.95	19.00
Cumulative variance (%)	36.12	70.08	89.08
pH	0.87	-0.17	-0.29
OM	-0.37	0.36	0.58
t	0.49	0.74	0.39
T	0.06	0.71	0.65
V%	0.93	0.33	0.03
m%	-0.96	-0.03	0.17
Sand	-0.47	0.61	-0.52
Clay	0.28	-0.80	0.51
Silt	0.05	0.82	-0.35

OM: organic matter; t: effective CEC; T: potential CEC; V%: base saturation; m%: aluminum saturation.

Organic matter (OM) was grouped in the same cluster as m%. Organic soils occur mainly in undrained sites, and pH generally decreases in saturated soils as the redox potential decreases as a result of microbial activity in the absence of molecular oxygen (BOYD 2020). The force of attraction of cations by colloids varies as a function of charge and the hydrated radius of the cation. The greater the charge and the smaller the hydrated radius, the more strongly the cation will be adsorbed. In saturated soils, colloids have a higher concentration of Al3+ since their attractive force is higher than that of Ca2+ or Mg2+, which are leached more easily (FASSBENDER 1987).

When considering only the lands, three groups were observed: the first group was formed by locations

4 and 5, the second group by the lands 1, 2 and 6, and the third group by the lands 3 and 7, which were further away from the others (Figure 5). Lands 3 and 7 showed lower pH and base saturation and higher aluminum saturation than the others. Except for lands 4 and 5, the others were built in floodplain locations and were closer to the cluster formed by the lands 1, 2 and 6. This shows that some factors are decisive when grouping lands based on soil characteristics and that it is not possible to generalize the lands in the decision-making of management, such as fertilization and liming, in addition to other factors of management that depend on the soil characteristics.

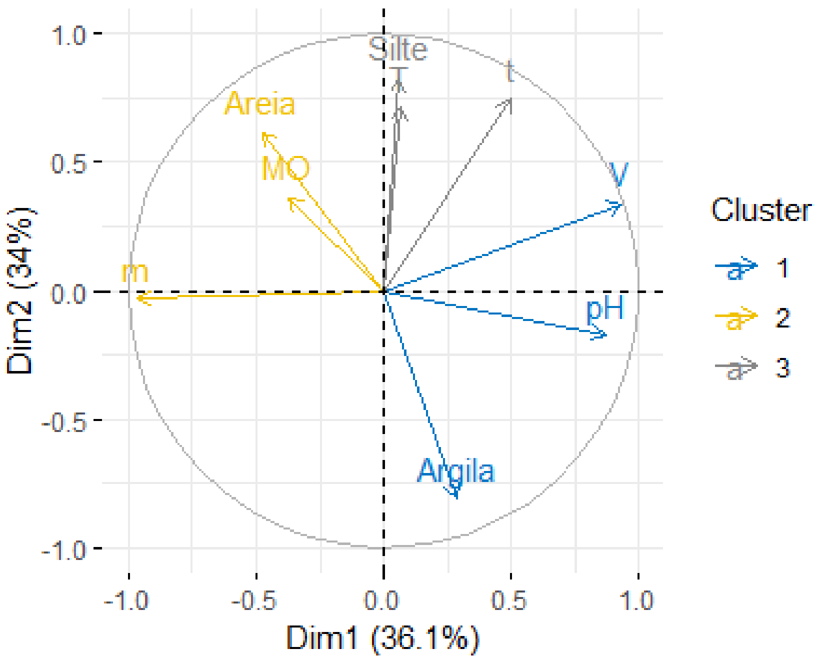

Figure 4. PCA ordering of physicochemical parameters and soil organic matter in fish farms in Dourados – MS, Brazil. V: base saturation; OM: organic matter; m: aluminum saturation; t: effective CEC; T: potential CEC.

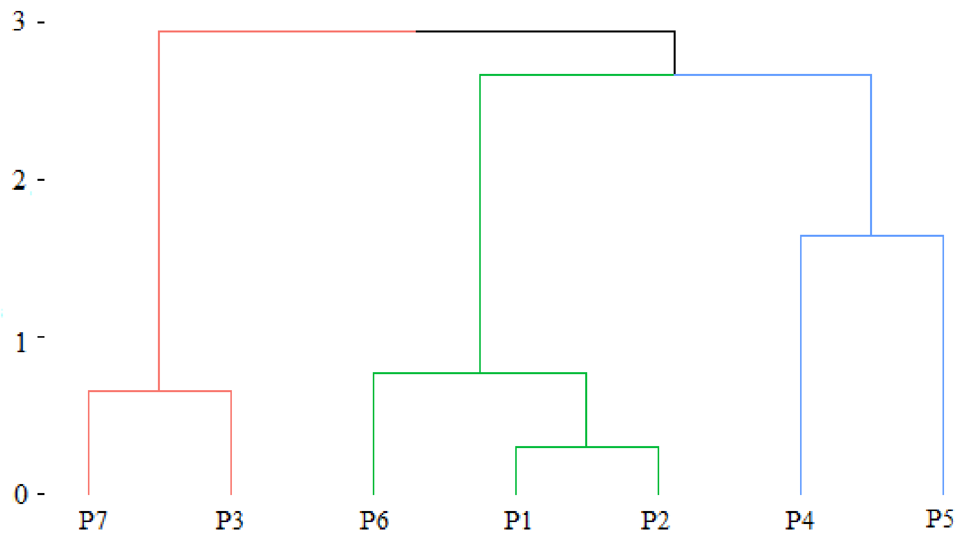

Figure 5. Dendrogram showing the similarity of fish farms in terms of soil characteristics.

Thus, it is possible to verify that the chemical and physical characteristics and the organic matter differentiate the lands. The study of the soil, mainly in terms of chemical parameters and organic matter, is still scarce in Brazilian fish farming. The results of the present work can help to elucidate the importance of studying soils for fish farming. Knowledge of this information is essential for a better decision making, both for choosing the place before the construction of the ponds and for management during production, such as liming the water in ponds.

CONCLUSION

The soils of the evaluated fish farms in Dourados have an acid pH in general, an adequate amount of clay for the construction of ponds, and base saturation is more representative than aluminum saturation and it was demonstrated that fish ponds built on a same terrain pattern, such as floodplains, may present differences in chemical, physical and organic matter composition in the soil.

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