FERTIGATION OF HUMIC SUBSTANCE: EFFECTS ON SOIL PROPERTIES OF A XANTHIC FERRALSOL (DENSIC)

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Keywords:
Nutritional management
Soil quality
Soil organic matter

ABSTRACT

The complexity of humic substances (HS) and their properties in agricultural applications have attracted the attention of many researchers. However, controversial results have been obtained, because of the difficulty in identifying a precise relationship between the structure and activity of these substances. This study aimed to evaluate the influence of different frequencies and concentrations of humic substances on the behavior of physical, chemical and microbiological soil attributes. The experiment was carried out at Embrapa Cassava and Fruticulture in Latossolo Amarelo Distrocoeso [(Xanthic Ferralsol (Densic); Oxisol], with a completely randomized block design with four repetitions in a split-plot scheme, with three application frequencies (F1 = 15 days, F2 = 30 days and F3 = 45 days) and four concentrations of humic substances (C1 = 0 ml.L-1, C2 = 3 ml.L-1, C3 = 6 ml.L-1 and C4 = 9 ml.L-1). The humic substance applied at a frequency of 45 days positively favored the physical and chemical attributes of the soil, mainly at concentrations of 6 and 9 ml.L-1, due to the increase in microporosity. This information can be used to improve the performance of agricultural practices, especially those related to soil preparation, use of agricultural inputs, water management, soil water content and, especially, soil management practices.

Palavras-chave:
Manejo nutricional
Qualidade do solo
Matéria orgânica do solo

FERTIRRIGAÇÃO DE SUBSTÂNCIA HÚMICA: EFEITOS NAS PROPRIEDADES DO SOLO DE UM LATOSSOLO AMARELO DISTRÓFICO COESO

RESUMO

A complexidade das substâncias húmicas (SH) e suas propriedades em aplicações agrícolas atrairam e continuam a chamar a atenção de muitos pesquisadores. No entanto, têm se obtido resultados controversos, por causa da dificuldade em identificar uma relação precisa entre a estrutura e a atividade dessas substâncias. Este estudo objetivou avaliar a influência de diferentes frequências e concentrações no comportamento dos atributos físicos e químicos do solo. O experimento foi realizado na Embrapa Mandioca e Fruticultura em Latossolo Amarelo Distrocoeso [Xanthic Ferralsol (Densic); Oxisol], com delineamento experimental em bloco inteiramente casualizado com quatro repitções em esquema de parcela subdividida, sendo três frequências de aplicação (F1 = 15 dias, F2 = 30 dias e F3 = 45 dias) e quatro concentrações de substâncias húmicas (C1 = 0 ml.L-1, C2 = 3 ml.L-1, C3 = 6 ml.L-1 e C4 = 9 ml.L-1). A aplicação da substância húmica aplicada na frequência de 45 dias favoreceu positivamente os atributos físico e químicos do solo, principalmente nas concentrações de 6 e 9 ml.L-1, em função do aumento da microporosidade. Essas informações que podem ser usadas para melhorar o desempenho das práticas agrícolas, principalmente aquelas relacionadas ao preparo do solo, uso de insumos agrícolas, manejo da água, teor de água no solo e, especialmente, as práticas de manejo do solo.
INTRODUCTION

Humic compounds or humic substances compose organic matter, exerting a great influence on the structure, water retention, microbial activity, storage and cycling of nutrients in the soil. The use of humic substances (HS) associated with the organomineral system has become a constant practice in current agricultural systems. However, it is difficult to find an recommended application that meets all the physical, chemical, and biological attributes of the soil, to the point of providing an adequate development for the crops (LAL, 2009).

Humic substances participate in the reactions that occur in the soil, acting in the chemical sphere and promoting the formation of organomineral complexes. Thus, they contribute to improved storage and availability of nutrients for crops and the physical environment of the soil, favoring aggregation along with the stability of aggregates in the soil (ZHANG et al., 2014; ZHONG et al., 2015; WANG et al., 2015).

Many researchers point out the beneficial effect of applying HS-based products to increase the efficiency of nutrient utilization in the soil-plant system. The effects of HS on plants depend on the materials that are formed; the concentrations of fulvic and humic acids; the doses used for each cultivar and the type of soil. The HS are composed of several functional groups that directly or indirectly affect the physical and chemical attributes of the soil (NEILSEN et al., 2004).

However, there are still few studies evaluating the effects of frequency and concentration of application of these products (OLK et al., 2018), which can leverage the necessary improvements to overcome the limiting factors in crop production. The application of a certain concentration of humic substances in the injection solution in fertigation, at a certain frequency, maximizes the effect of the substances on crop productivity and on the physical, chemical and biological attributes of the soil. This study, therefore, aimed to evaluate the effect of humic substances (HS) applied at different frequencies and concentrations on physical, chemical and microbiology attributes of a Xanthic Ferralsol (Densic).

MATERIAL AND METHODS

The experiment was performed in a greenhouse of the experimental area of Embrapa Cassava and Fruits, located in Cruz das Almas, Bahia (12º 40’19”S and 39º 06’ 22”W). The soil was, classified as Xanthic Ferralsol (Densic) (SOUZA & SOUZA, 2001), with a sandy clay loam texture (641 g kg⁻¹ sand, 85 g kg⁻¹ silt, 274 g kg⁻¹ clay), was collected in a 0-0.30 m layer in the experimental area for physical and chemical analyses (Table 1), in the period from 01/2016 to 09/2016.

Table 1. Physical and chemical attributes of the soil in the experimental area referring to a depth of 0-0.30 m. Cruz das Almas, BA, 2016

| Physical attributes of soil ¹ | Particle size composition (g kg⁻¹) Dispersion with NaOH | Water retention - Ug (cm³ cm⁻³) |
|-------------------------------|--------------------------------------------------------|-------------------------------|
| Dep.(m)                      | VCS          | CS   | MS   | TS   | VFS | T.S. | Silt | Clay | Textural classification |
| 0-0.30                       | 22.87        | 181.52 | 256.32 | 141.35 | 51.10 | 653.16 | 78.98 | 267.86 | sandy clay loam         |
| TP                            | 0.595        | 0.167 | 0.428 | 1.730 | 0.180 | 0.165 | 0.155 | 0.146 | 0.024                  |
| MacP                          | 0.06 atm     | 0.10 atm | 0.33 atm | 3.00 atm | 15.00 atm | A.W. |
| MicP                          |              |       |       |       |       |       |       |       |                        |
| Bd                            |              |       |       |       |       |       |       |       |                        |
| Water retention              |              |       |       |       |       |       |       |       |                        |

| Soil chemical attributes²    |
|-------------------------------|
| Dep.(m)                      | pH | P | K | Ca+Mg | Ca | Mg | Al | H+Al | Na | BS | CTC | V | O.M |
| 0-0.30                       | 5.34 | 6.50 | 41.50 | 2.35 | 1.55 | 0.80 | 0.10 | 2.60 | 0.04 | 2.50 | 5.10 | 48 | 10.45 |

¹- VCS - Very Coarse Sand; CS - Coarse Sand; MS - Medium Sand; TS - Thin Sand; VFS - Very Fine Sand; T.S. - Total Sand; TP - Total Porosity; MacP - Macroporosity; MicP - Microporosity; Bd - Bulk density; A.W. - Available Water.

²- pH - Hydrogen Potential; P - Phosphorus; K - Potassium; Ca+Mg - Calcium + Magnesium; Ca - Calcium; Mg - Magnesium; Al - Aluminium; H+Al - Hydrogen + Aluminium; Na - Sodium; BS - Sum of Base; CTC - Cation Exchange Capacity; V - Base Saturation; O.M - Organic Matter.

Eng. Agric., v.30, p.222-235, 2022
The experimental units were composed of PVC columns (0.10 m diameter and 0.30 m height), together with the solution extractors, installed at a depth of 0.15 m. Soil moisture monitoring was estimated by the gravimetric method with water replacement to keep the soil at the moisture corresponding to the soil’s field capacity.

The humic used was a product derived from Leonardite. A completely randomized design with four repetitions was used, evaluating three application frequencies (plot), four concentrations of humic substances (subplot) and the interaction between these two factors during two cultivation cycles (1st and 2nd) of the “Grande Naine” banana tree. The application frequencies were: F1 = 15 days, F2 = 30 days and F3 = 45 days, and the concentrations of HS diluted in water: C1 = 0 ml L⁻¹, C2 = 3 ml L⁻¹, C3 = 6 ml L⁻¹ and C4 = 9 ml L⁻¹. Soil solutions were collected before each application using soil solution extractors.

The effect of HS on the physical attributes of the soil were determined by evaluating the total porosity, macroporosity and microporosity; soil density; aggregate stability (wet and dry) and weighted average diameter (wet) (TEIXEIRA et al., 2017).

The analyses of the chemical attributes of the soil determined the concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), sodium (Na), potential acidity (H⁺Al), calculation of sum of bases (SB), cation exchange capacity (CTC), base saturation (V%) and organic matter content. For the soil solution variables, the concentrations of nitrate (NO₃⁻), sodium and potassium and the electrical conductivity of the saturation extract were obtained. All these analyses were performed according to Teixeira et al. (2017). The following soil microbiological properties were determined: microbial biomass carbon (MBC), (VANCE et al., 1987); microbial biomass respiration (MBR) (JENKINSON, 1966) and metabolic coefficient (qCO₂) (ANDERSON & DOMSCH, 1986).

Data were submitted to classic descriptive statistical analysis. In the statistical analysis, the Kolmogorov-Smirnov (KS) test was applied to verify the normality of the data, the F test was performed for the analysis of variance, the Tukey test was used for the comparison of means at 5% of probability and the regression analysis was also performed when appropriate. The statistical analyses were performed using the R beta software. For exploratory data analysis, principal component analysis (PCA) was performed for soil physical and chemical properties. Principal component analysis allows a better understanding of the multivariate behavior of different characteristics by separating the areas in response to soil variables (HAIR JÚNIOR et al., 2009). Biplot graphs were created using Soft Statistica for Windows (Version 8.0, Stat Soft Inc, Tulsa, EUA), to interpret PC analysis.

RESULTS AND DISCUSSION

Statistical results

Among the physical variables of the soil evaluated, it was possible to observe that the joint action of the frequency of application and concentration of humic substances positively affected the stability of aggregation in water, it was possible to evaluate the positive effect of the concentration of humic substances on variables weighted average diameter (WAD), aggregate stability in water, soil density, macroporosity and microporosity, being variables that allow us to make inferences about the effect of treatments on the structural aspect of the soil (Table 2).

The concentrations of nitrate (NO₃⁻) in the soil solution was significantly influenced by the frequency of application and concentration of the HS-based product, while the electrical conductivity (EC – dS.m⁻¹) and potassium (K⁺) were not significantly affected by treatments (Table 3).

As for microbiological variables, microbial biomass carbon (MBC) showed a difference between HS application frequency and concentration. However, microbial biomass respiration (MBR) and metabolic coefficient (COEF) were not significantly affected by treatments.

Effect of frequency application and concentration of hs-based product on soil physical properties.

The isolated effect of HS concentration on aggregate stability index (ASI) was verified (Figure 1). This index reflects the relationship between wet/dry stability and aggregates: the closer to 1.0, the greater the aggregate stability and the greater the resistance of soil to soil-disturbing external factors (LUCIANO et al., 2010)).
Humic substances play a role in cementing soil particles and promoting higher aggregate stability (GOEBEL et al., 2011; VASCONCELOS et al., 2010; OLIVEIRA et al., 2013). This effect occurs because, according to Perusi et al. (2008), soil organic matter provides greater stability to soil aggregates sieved in water, while clay content helps aggregating the soil in dry sieving. The highest ASI was measured at a concentration of approximately 4.5 ml L⁻¹. However, beyond this point, ASI decreased with the increase in concentration.

High HS concentrations may reduce the interaction between HS fraction and clay fraction in tropical soils (ASSIS et al., 2006) affecting the ASI / HS ratio. The fact that the HS fraction has greater carbon content than the others may be related to the lower stability of organic carbon, fulvica acid (C-FAF), and humic acid (C-HAF) fractions affecting the movement of carbon in the soil profile, polymerization or mineralization. These changes decrease the soil carbon content (LEITE et al., 2003; FONTANA et al., 2006), which becomes

| Source of Variation | W.A.D. H₂O (mm) | S.A.w (%) | S.A.d (%) | A.S.I (%) | D.F (kg dm⁻³) | Bd (kg dm⁻³) | MacP (m³ m⁻³) | MicP (m³ m⁻³) | TP (m³ m⁻³) |
|---------------------|-----------------|-----------|-----------|-----------|---------------|-------------|--------------|--------------|-------------|
| Frequency           | 0.13<sup>ns</sup> | 110.2<sup>ns</sup> | 24.1<sup>ns</sup> | 0.01<sup>ns</sup> | 62.1<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> |
| Concentration       | 0.76<sup>*</sup> | 591.7<sup>ns</sup> | 94.7<sup>ns</sup> | 0.03<sup>ns</sup> | 18.8<sup>ns</sup> | 0.01<sup>ns</sup> | 0.01<sup>ns</sup> | 0.01<sup>ns</sup> | 0.00<sup>ns</sup> |
| Frequency x Concentration | 0.45<sup>ns</sup> | 485.9<sup>ns</sup> | 39.7<sup>ns</sup> | 0.10<sup>ns</sup> | 35.5<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> | 0.00<sup>ns</sup> |
| Error               | -               | -         | -         | -         | -             | -           | -            | -            | -           |
| Total               | 1.31           | 48.60     | 85.44     | 0.62      | 6.15          | 1.55        | 0.09         | 0.29         | 0.38        |

**Significant (p≤0.01); *significant (p≤0.05). CV - Coefficient of Variation; DF - Degree of Freedom; W.A.D - Wet Weighted Average Diameter; S.A.w - Stability of Aggregates wet; S.A.d - Stability of Aggregates via dry process; A.S.I - Aggregate Stability Index; D.F: Degree of Flocculation; Bd - Bulk density; MacP - Macroporosity; MicP - Microporosity; TP - Total Porosity

Table 3. Analysis of variance with mean squares, significance levels, means and coefficients of variance for soil solution chemical attributes evaluated in two cycles of ‘Grande Naine’ banana at the 0- to 0.30-m depth

| Source of variation | K (mg L⁻¹) | NO₃⁻ (g L⁻¹) | EC (dS m⁻¹) |
|---------------------|------------|--------------|-------------|
| Block               | 0.61<sup>ns</sup> | 100.01<sup>ns</sup> | 0.13<sup>ns</sup> |
| Cycle               | 0.50<sup>ns</sup> | 175.14<sup>ns</sup> | 0.32<sup>ns</sup> |
| Frequency           | 0.47<sup>ns</sup> | 114.18<sup>ns</sup> | 0.48<sup>ns</sup> |
| Cycle*Frequency     | 0.06<sup>ns</sup> | 710.13<sup>ns</sup> | 0.13<sup>ns</sup> |
| CV (%)              | 62.55      | 19.03        | 19.74       |
| Concentration       | 0.06<sup>ns</sup> | 145.98<sup>ns</sup> | 0.05<sup>ns</sup> |
| Cycle*Concentration | 0.30<sup>ns</sup> | 195.63<sup>ns</sup> | 0.22<sup>ns</sup> |
| CV (%)              | 17.72      | 6.18         | 11.07       |
| Frequency*Concentration | 0.61<sup>ns</sup> | 970.11<sup>ns</sup> | 0.96<sup>ns</sup> |
| CV (%)              | 43.34      | 23.95        | 31.01       |
| Frequency *Concentration*Cycle | 0.15<sup>ns</sup> | 859.69<sup>ns</sup> | 0.21<sup>ns</sup> |
| Overall mean        | 0.06       | 220.07       | 0.48        |

**Significant (p< 0.001); *significant (p <0.05). CV - Coefficient of Variation; K - Potassium; Na - Sodium; NO₃⁻ - Nitrate; EC - Electrical Conductivity
unevenly distributed in the soil, thereby causing different behaviors in this type of environment (ROSSET et al., 2016).

The fact that the HS fraction has greater carbon content than the others may be related to the lower stability of organic carbon, fulvic acid (C-FAF), and humic acid (C-HAF) fractions affecting the movement of carbon in the soil profile, polymerization or mineralization. These changes decrease the soil carbon content (LEITE et al., 2003; FONTANA et al., 2006), which becomes unevenly distributed in the soil, thereby causing different behaviors in this type of environment (ROSSET et al., 2016).

**Effect of application frequency and concentration of HS on potassium, nitrate and sodium contents, and electrical conductivity in soil solution**

Based on the interaction between concentrations and cycles (Figure 2) for potassium content in soil solution, concentrations close to 6 mL.L⁻¹ were found to increase potassium concentration from the first to the second cycle. The highest potassium concentration in the second cycle may be associated with the residual effect of potassium fertilizer applied to soil in the first banana cycle. Humic substance concentrations of 5.15 and 5.45 mL.L⁻¹ led to the highest potassium concentration.

**Figure 1.** Aggregate Stability Index (ASI) under different HS concentrations for ‘Grande Naine’ banana

**Figure 2.** Potassium content in soil solution under different HS concentrations and two banana crop cycles at 0- to 0.30- m depth. Cruz das Almas, BA. 2016
in the soil solution for the first and second cycles, respectively.

According to Duval et al. (1998), soil potassium concentration may increase due to the application of leonardite. Accordingly, the authors reported higher K levels in soil that received leonardite compared with the control. In general, HS type and different humic compound extraction techniques and processes are factors promoting changes in chemical composition and bioactivity of nutrients, which may cause negative effects at certain concentrations (HARTZ & BOTTOMS, 2010). The interaction between chemical composition of HSs and bioactivity has been studied (CANELLAS et al., 2009; AGUIAR et al., 2013; MARTINEZ-BALMORI et al., 2014) and the importance of hydrophobic / hydrophilic relationship was found to be a key indicator to predict bioactivity based on its chemical properties together with nutrient enrichment.

Additionally, in systems with low input of organic acids, K\(^+\) tends to be more mobile in the soil solution than bivalent ions such as Ca\(^{2+}\) and Mg\(^{2+}\). This occurs because K\(^+\) has lower valence and greater association constant with inorganic anions, so K\(^+\) is more prone to leaching (FRANCHINI et al., 2003; DUIKER & BEEGLE, 2006).

The effect of HS concentrations at each application frequency on nitrate concentration is shown in Figure 3. The results reveal that HS concentrations between 3 mL.L\(^{-1}\) and 6 mL.L\(^{-1}\) improve nitrate concentration in the soil solution, as similarly observed for potassium. However, the nitrate concentration is higher when applying HS every 15 days (F1).

Figure 3. Nitrate content (NO\(_3\)^-\) as a function of application frequency at each concentration of HS. Cruz das Almas, BA. 2016

Regarding the effect of concentration and application frequency of HS on soil chemical attributes, the results from the analysis of variance revealed that the application of HSs significantly affected calcium concentration and organic matter content (OM).

According to Beauclair et al. (2010) and Baldotto and Baldotto (2014), the release of organic acids from organic matter may increase the concentration of nutrient ions in the soil due to an increase in negatively charged organic radicals, which reduces leaching of nutrient ions. In addition, the soil nutrients content such as phosphorus tends to rise since organic molecules interact with ion exchange sites such as aluminum, which would otherwise fix and make phosphorus unavailable to plants.

Furthermore, Selim et al. (2009) and Selim and Mosa (2012), who evaluated HS application through fertigation with superficial and subsurface drip systems, on sandy soils cultivated with potato, reported that HS application reduced leaching of nutrients such as potassium and nitrogen. However, Melo et al. (2016) found no positive effects of fertigation with HS on properties of a xanthic ferralsol (densic) cultivated with banana.

Electrical conductivity (EC) in the soil solution was not significantly affected by treatments. However, previous studies on the application of HS-based product indicated that the increase in the amount and concentration of humic acids may be

\[
\gamma(F1) = -3.3841x^2 + 34.888x + 165.05\quad R^2 = 0.92
\]

\[
\gamma(F2) = -2.4766x^2 + 25.907x + 166.08\quad R^2 = 0.98
\]
accompanied by an increase in soil pH, nutrient levels, and EC in the soil solution (YILMAZ, 2010; GÜMÜŞ & SEKER, 2015).

**Effect of application frequency and concentration of HS on soil microbiological attributes**

A significant effect of HS concentration on microbial biomass carbon was observed and fitted to a quadratic model (Figure 4). It is observed the gradual increase of MBC with the increase in concentration of the HS-based product (Figure 4) as reported in studies performed by Wei et al., 2015; Medina et al., 2015; Ma et al., 2016; Zheng et al., 2016.

Applying HS-based products may directly affect root morphology and physiology but may also has an indirect impact on the chemistry and microbial dynamics within the rhizosphere by stimulating the exudation of organic acids and increasing the microbial population (CANELLAS et al., 2008). Similarly, Almeida et al. (2018) noted that the transport of gases within the soil depends on soil porosity, which governs processes of oxygen entry and CO₂ emission for the aerobic activity of microorganisms.

Organic carbon incorporated into the soil by humic compounds positively influence microbiological characteristics of soil, as similarly reported in laboratory (LUO et al., 2013) and field experiments (CHEN et al., 2013; ZHENG et al., 2016), in which the application of HS increased microbial biomass. Microbial biomass is considered the living and most active portion of the soil’s organic matter (ROSCOE et al., 2006; SINGH et al., 2011). Higher microbial carbon content leads to greater temporary immobilization of nutrients and, consequently, decrease loss of nutrients through processes such as leaching (NOVAK et al., 2017).

Conversely, there is no consensus on the mechanisms of action of these organic acids on plants. Although different plant responses to concentration, molecular weight, organic acid structure and HS sources are known (MUSCOLO et al., 2013), discussing the effects at a physiological level is often complicated or even inconclusive, especially under uncontrolled conditions, such as those normally found in field experimentation; so there is a shortage of works on this topic (ZANDONADI et al., 2013).

**Principal component analysis of physical-chemical properties of the soil**

According to Ribas and Vieira (2011), the goal of principal component analysis (PCA) is achieved when a relatively small number of extracted components can explain most variability in the original data. Soil variables in 0-30 cm layer explain 62.93% of data variation for the two principal components (PC1 and PC2) (Table 4). The eigenvalue for PC1 is 0.4160, which means that the

![Figure 4](image)

**Figure 4.** Microbial Biomass Carbon as affected by HS-based product at the concentration 0-, 3-, 6- and 9-ml L⁻¹. Cruz das Almas, BA. 2016
first component explains 41.60% of total variance. Similarly, the eigenvalue for PC2 is 0.2133, i.e.,
the second component explains 21.33% of total variance.

Correlation coefficients of the variables of greatest importance are in PC1, as well as
eigenvalues of components (Table 4). Therefore,
the treatments were sufficiently strong to affect positively these important variables responsible
for maintaining and/or raising physical-chemical attributes evaluated in the soil. Principal
components must be greater than 0.60 and must be expressed as a non-negative value to establish
a significant correlation to the variables. All variables measured in the studied soil had a
correlation equal to or greater than 0.60. In PC1,
the variables: MicP, TP, K, Ca, Mg, Ca + Mg, Na, H + Al had values above 0.60 and the greatest
influence in the analysis since they exert a weight on PC1. However, variables physical of soil such
as Aggregate stability via dry (ASI1), Aggregate
stability via wet (ASI2) and variables chemical of
soil pH and P were affected differently, showing
low interaction among variables in the analysis
(Table 5).

Resende et al., (2012), when evaluating soil
physical characteristics under different land use,
concluded that the area with organic residues stored
more organic matter (OM), reflecting on better
soil physical attributes, including macroporosity, density and total porosity. Conversely, agricultural
areas with lower OM stores lost soil physical

Table 4. Eigenvalues and variation explained by each component

|        | Eigenvalue | Total Variation (%) | Total eigenvalue | Total variation (%) |
|--------|------------|---------------------|------------------|---------------------|
| *PC1   | 7.49       | 41.60               | 7.49             | 41.60               |
| *PC2   | 3.84       | 21.33               | 11.33            | 62.93               |

*PC1 (principal component 1); PC2 (principal component 2)

Table 5. Correlation between each principal component and soil physical-chemical properties

| Variables          | PC1     | PC2     |
|--------------------|---------|---------|
| Bd                 | 0.59    | 0.51    |
| MacP               | 0.33    | 0.61    |
| MicP               | 0.85    | 0.39    |
| Pt                 | 0.83    | 0.24    |
| ASI1               | 0.08    | 0.12    |
| ASI2               | 0.09    | 0.09    |
| pH                 | 0.30    | 0.58    |
| P                  | 0.53    | 0.09    |
| K                  | 0.87    | 0.09    |
| Ca                 | 0.78    | 0.43    |
| Mg                 | 0.67    | 0.58    |
| Ca+Mg              | 0.78    | 0.53    |
| Na                 | 0.71    | 0.43    |
| H+Al               | 0.06    | 0.88    |
| BS                 | 0.88    | 0.05    |
| CEC                | 0.84    | 0.34    |
| V                  | 0.25    | 0.85    |
| OM                 | 0.85    | 0.14    |

Bd - Bulk density (g cm⁻³); MacP - Macroporosity (cm³ cm⁻³); MicP - Microporosity (cm³ cm⁻³); TP - Porosity (cm³ cm⁻³); ASI1 - Aggregate Stability via dry; ASI2 - Aggregate Stability via wet; pH - Potential of Hydrogen; P - Phosphorus (mg dm⁻³); K - Potassium (cmolc dm⁻³); Ca - Calcium (cmolc dm⁻³); Mg - Magnesium (cmolc dm⁻³); Ca + Mg - Calcium + Magnesium; Na - Sodium (cmolc m⁻³); H + Al - Potential acidity; BS - Sum of bases (cmolc dm⁻³); CEC - Cation Exchange Capacity (cmolc dm⁻³); V% - Percentage of base saturation; OM - Organic Matter (g kg⁻¹)
quality. Soil organic matter, when maintained and/or increased in environments containing plant biodiversity, supplies nutrients through the mineralization of its humic fractions. This is one of the main responsible for the soil’s cation exchange capacity (CEC) as humic forms, especially in weathered soils, since nutrients are slowly released into the soil, providing the plants with nutrients taken up by crops (PRIMO et al., 2011; QUEIROZ et al., 2019).

As can be seen in Figure 5, the variables that superimposed on each other and are closer to middle of the circle are representative variables in the graph.

The greater the length of a vector, the more influential it will be for the analysis (BORCARD et al., 2011). By analyzing how variables are distributed on the graph shown in Figure 5, we can see that treatments applied over the second cycle have a greater influence on physical properties associated with porosity (Bd, MicP and TP) and are the most representative among the variables evaluated. Bd and TP have a direct relationship: the greater the Bd, the lower the porosity (CARVALHO et al., 2018).

Therefore, the treatments, in the analysis of PC1 and PC2, highlighted the most influential variables, and we can conclude that the attributes V, pH, Ca,
Mg, Ca + Mg, BS, OM were grouped in quadrant I while CEC, P, K, Na, MacP were grouped in quadrant IV.

**CONCLUSIONS**

- According to the results we can conclude that the K content in the soil solution was higher in the second cycle at the concentration of 6 mL L⁻¹, while the NO₃⁻ content in the soil solution had better results at the frequency of 15 days at the same concentration. Electrical conductivity was not affected by the treatments evaluated.

- The microbial biomass carbon showed the best result at a concentration of 5.31 mL L⁻¹ with a value of 217 (mgSS kg⁻¹). Regarding the aggregate stability index (ASI) was obtained the highest value of 0.9 with dose of 4.85 (mm).

- The addition of HS-based compost to the soil during the two crop cycles at concentrations of 3 mL L⁻¹ and 6 mL L⁻¹ and at a application frequency of 45 days increases the levels of potassium and nitrate in the soil solution.

- The multivariate analysis allows differentiating areas, highlighting the physical and chemical attributes influenced by the application of humic substances in ‘Grande Naine’ banana trees.

**DEVELOPMENT**

**AUTHORSHIP CONTRIBUTION STATEMENT**

PEREIRA, B.L.S.: Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing; COELHO, E.F.: Conceptualization, Resources, Validation, Writing – original draft, Writing – review & editing; XAVIER, F.A.S.: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing; SOUZA, L.D.: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing; SOUZA, L.S.: Data curation, Investigation, Visualization, Writing – original draft, Writing – review & editing.

**DECLARATION OF INTERESTS**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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