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

Bruno Laecio da Silva Pereira[1]* (ID), Eugenio Ferreira Coelho[2] (ID), Francisco Alisson da Silva Xavier[2] (ID), Laercio Duarte Souza[2] (ID) & Luciano Silva Souza[1] (ID)

1 - Postgraduate Program in Agricultural Engineering, Federal University of Recôncavo da Bahia, Cruz das Almas, BA, Brazil

2 - Embrapa Mandioca e Fruticultura, Brazilian Agricultural Research Corporation, Cruz das Almas, BA, Brazil

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.

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 atraíram 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 repetições 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, nas 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												
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	MacP	MicP	Bd	Water retention - Ug (cm³ cm⁻³)							
Dep.(m)	cm³ cm⁻³			g cm⁻³	0.06 atm	0.10 atm	0.33 atm	3.00 atm	15.00 atm	A.W.		
0-0.30	0.595	0.167	0.428	1.730	0.180	0.165	0.155	0.146	0.141	0.024		
Soil chemical attributes[2]												
Dep.(m)	pH	P	K	Ca+Mg	Ca	Mg	Al	H +Al	Na	BS	CTC	V	O.M
		mg dm⁻³		cmol$_c$ dm⁻³								%	g dm⁻³
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; TS - 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 + Aluminum; Na - Sodium; BS - Sum of Base; CTC - Cation Exchange Capacity; V - Base Saturation; O.M - Organic Matter

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 (NO$_3^-$), 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 (NO$_3^-$) 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)).

Table 2. Mean squares, coefficients of variation and general average for the physical attributes of the soil, evaluated at the end of the experiment, Cruz das Almas, BA, 2016

Source of Variation	DF	W.A.D. H_2O (mm)	S.A.w (%)	S.A.d (%)	A.S.I	D.F (%)	Bd (kg dm^{-3})	MacP (m^3 m^{-3})	MicP (m^3 m^{-3})	TP (m^3 m^{-3})
Frequency	2	0.13^{ns}	110.2^{ns}	24.1^{ns}	0.01^{ns}	62.1*	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}
Concentration	3	0.76*	591.7*	94.7^{ns}	0.03^{ns}	18.8^{ns}	0.01*	0.01**	0.01*	0.00^{ns}
Frequency x Concentration	6	0.45^{ns}	485.9*	39.7^{ns}	0.10*	35.5^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}
Error	36									
Total	47	-	-	-		-	-	-	-	-
CV1 (%)	-	40.07	34.34	8.78	21.31	51.78	5.37	35.49	16.77	17.96
CV2 (%)		33.84	27.29	7.22	29.22	74.75	3.35	36.47	8.08	8.77
Mean		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})	NO$_3^-$ (g L^{-1})	EC (dS m^{-1})
Block	0.61^{ns}	100.01^{ns}	0.13^{ns}
Cycle	0.50^{ns}	175.14*	0.32^{ns}
Frequency	0.47^{ns}	114.18*	0.48^{ns}
Cycle*Frequency	0.06^{ns}	710.13^{ns}	0.13^{ns}
CV (%)	62.55	19.03	19.74
Concentration	0.06^{ns}	145.98**	0.05^{ns}
Cycle*Concentration	0.30*	195.63^{ns}	0.22^{ns}
CV (%)	17.72	6.18	11.07
Frequency*Concentration	0.61^{ns}	970.11*	0.96^{ns}
CV (%)	43.34	23.95	31.01
Frequency *Concentration*Cycle	0.15^{ns}	859.69^{ns}	0.21^{ns}
Overall mean	0.06	220.07	0.48

**significant (p< 0.001); *significant (p <0.05). CV - Coefficient of Variation; K - Potassium; Na - Sodium; NO$_3^-$ - Nitrate; EC - Electrical Conductivity

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

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, 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 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
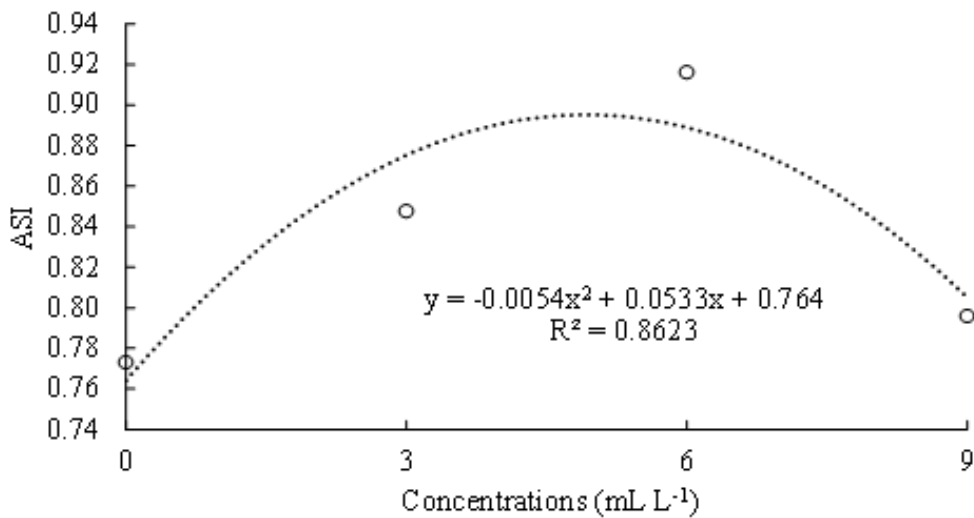

Figure 1. Aggregate Stability Index (ASI) under different HS concentrations for 'Grande Naine' banana mL L^{-1}

The equation shown in Figure 1:
$$y = -0.0054x^2 + 0.0533x + 0.764$$
$$R^2 = 0.8623$$

The equations shown in Figure 2:
$$y(1^a\ cycle) = -0.001x^2 + 0.0083x + 0.0441$$
$$R^2 = 0.887$$
$$y(2^a\ cycle) = -0.0013x^2 + 0.0129x + 0.0523^{**}$$
$$R^2 = 0.662$$
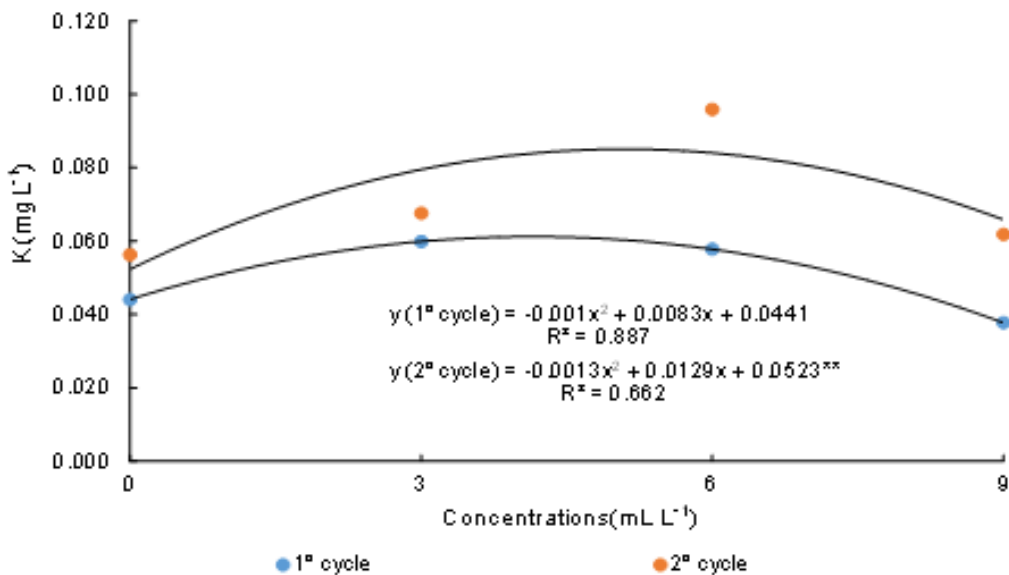
● 1ª cycle   ● 2ª cycle

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).

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
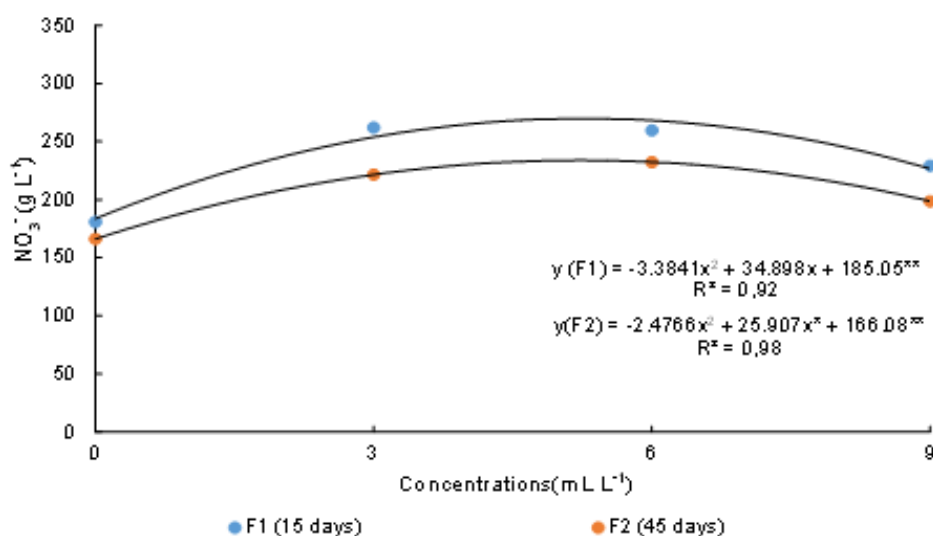

Figure 3. Nitrate content (NO$_3^-$) as a function of application frequency at each concentration of HS. Cruz das Almas, BA. 2016

accompanied by an increase in soil pH, nutrient levels, and EC in the soil solution (YILMAZ, 2010; GÜMÜS & 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 CO_2 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
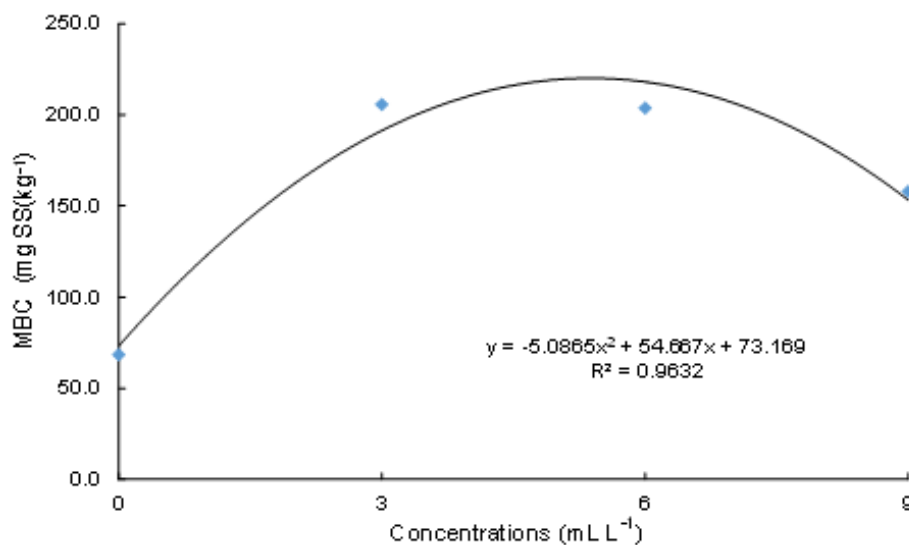

Figure 4. Microbial Biomass Carbon as affected by HS-based product at the concentration 0-, 3-, 6- and 9-ml L⁻¹. Cruz das Almas, BA. 2016

The plotted equation reads: $y = -5.0865x^2 + 54.667x + 73.169$, $R^2 = 0.9632$

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

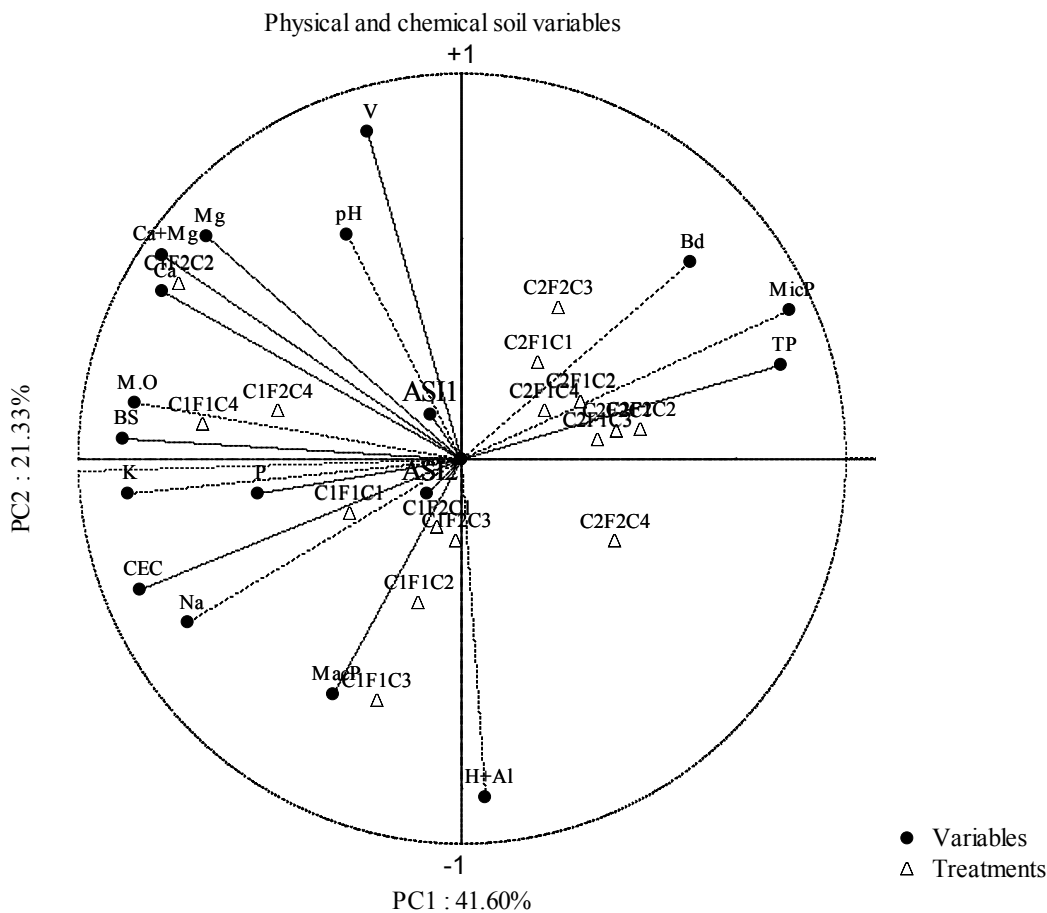Bd - Bulk density (g cm^{-3}); MacP Macroporosity (cm^3 cm^{-3}); MicP – Microporosity (cm^3 cm^{-3}); TP - Porosity (cm^3 cm^{-3}); ASI1 - Aggregate Stability via dry; ASI2 - Aggregate Stability via wet; pH - Potential of Hydrogen; P - Phosphorus (mg dm^{-3}); K - Potassium (cmolc dm^{-3}); Ca - Calcium (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,

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)

Figure 5. Scatterplot (biplot graph) created by analysis of principal components for physical-chemical attributes of soil as affected by treatments

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 NO_3^- 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.

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.

REFERENCES

AGUIAR, N. O.; NOVOTNY, E. H.; OLIVEIRA, A. L.; RUMJANEK, V. M.; OLIVARES, F. L.; CANELLAS, L. P. Prediction of humic acids bioactivity using spectroscopy and multivariate analysis. **Journal of Geochemical Exploration**, v. 129, p. 95-102, 2013.

ALMEIDA, R. F.; TEIXEIRA, D. B.; MONTANARI, R.; BOLONHEZI, A. C.; TEIXEIRA, E.B.; MOITINHO, M. R.; PANOSSO, A. R.; SPOKAS, K. A.; LA SCALA JÚNIOR, N. Ratio of CO2 and O2 as index for categorising soil biological activity in sugarcane areas under contrasting straw management regimes. **Australian Journal of Soil Research**, v. 56, p. 373-381, 2018.

ANDERSON, T. H.; DOMSCH, K. H. Carbon assimilation and microbial activity in soil. **Journal of Plant Nutrition and Soil Science**. Berlin, v. 149, p. 457-468, 1986.

ASSIS, C. P.; JUCKSCH, I.; MENDONÇA, E. de S.; NEVES, J. C. L. Carbono e nitrogênio em agregados de Latossolo submetido a diferentes sistemas de uso e manejo. **Pesquisa Agropecuária Brasileira**, Brasília, v. 41, p.1541-1550, 2006.

BALDOTTO, M. A.; BALDOTTO, L. E. B. Ácidos húmicos. **Revista Ceres**, Viçosa, v. 61, p. 856-881, 2014.

BEAUCLAIR, E. G. F.; GULLO, M. J. M.; TOMAZ, H. V. Q.; SCARPARI, M. S.; OTAVIANO, J. A. Uso de condicionador de solo a base de ácido húmico na cultura da cana-de-açúcar. **STAB**, Piracicaba, v. 28, p. 42-45, 2010.

BORCARD, D.; GILLET, F.; LEGENDRE, P. **Numerical Ecological with R**. New York: Springer, 2011.

CARVALHO, M. A. C.; PANOSSO, A. R.; TEIXEIRA, E. E. R.; ARAÚJO, E. G., BRANCAGLIONI, V. A.; DALLACORT, R. Multivariate approach of soil attributes on the characterization of land use in the southern Brazilian Amazon. Amsterdam. **Soil and Tillage Research**, v. 184, p. 207-215, 2018.

CANELLAS, L. P.; SPACCINI, R.; PICCOLO, A.; DOBBSS, L. B.; OKOROKOVA-FAÇANHA, A. L.; SANTOS, G. D. A. Relationships between chemical characteristics and root growth promotion of humic acids isolated from Brazilian oxisols. **Soil Science,** v. 174, p. 611-620, 2009.

CANELLAS, L. P.; TEIXEIRA JUNIOR, L. R. L.; DOBBSS, L. B.; SILVA, C. A.; MÉDICI, L. O.; ZANDONADI, D. B.; FAÇANHA, A. R. Humic acids crossinteractions with root and organic acids. **Annals of Applied Biology**, v. 153, p. 157-166, 2008.

CHEN, J. H.; LIU, X. Y.; ZHENG, J. W.; ZHANG, B. LU, H. F.; CHI, Z. Z.; PAN, G. X.; LI, L. Q.; ZHENG, J. F.; ZHANG, X. H.; WANG, J. F.; YU, X. Y. Biochar soil amendment increased bacterial but decreased fungal gene abundance with shifts in community structure in a slightly acid rice paddy from Southwest China. **Applied Soil Ecology**, v. 71, p. 33-44, 2013.

DUVAL, J. R.; DAINELLO, F. J.; HABY, V.A.; EARHART, D.R. Evaluating leonardite as a crop growth enhancer for turnip and mustard green. **Horticultural Science and Technology**, v.8, p. 564-567, 1998.

DUIKER, S. W.; BEEGLE, D. B. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. **Soil and Tillage Research.** v. 88, p. 30-41, 2006.

FONTANA, A. P.; MARCOS G.; LOSS, A.; CUNHA, T. J. F.; SALTON, J. C**.** Atributos de fertilidade e frações húmicas de um Latossolo Vermelho no Cerrado. **Pesquisa Agropecuária Brasileira**, Brasília, v. 41, n. 5, p. 847-853, 2006.

FRANCHINI, J.C.; HOFFMANN-CAMPO, C. B.; TORRES, E.; MIYAZAWA, M.; PAVAN, A. Organic composition of green manure during growth and its effect on cation mobilization in an acid Oxisol. **Communications in Soil Science and Plant Analysis**, v. 34, p. 2045-2058, 2003.

GOEBEL, M. O.; BACHMANN, J.; REICHSTEIN, M.; JANSSENS, I. A.; GUGGENBERGER, G. Soil water repellency and its implications for organic matter decomposition: is there a link to extreme climatic events?. **Global Change Biology**, v. 17, p. 2640-2656, 2011.

GÜMÜS, I.; ŞEKER, C. Influence of humic acid applications on modulus of rupture, aggregate stability, electrical conductivity, carbon and nitrogen content of a crusting problem soil. **Solid Earth**, v. 6, p. 1231-1236, 2015.

HARTZ, T. K.; BOTTOMS, T. G. Humic substances generally ineffective in improving vegetable crop nutrient uptake or productivity. **HortScience**, v. 45, p. 906-910. 2010.

HAIR JÚNIOR., J. F.; BLACK, W. C.; BABIN, B. J.; ANDERSON, R. E.; TATHAM, R. L. **Análise multivariada de dados**. 6.ed. Porto Alegre:Bookman, 2009.

JENKINSON, D.S. Studies on decomposition of plant material in soil 2: partial sterilization of soil and soil biomass. **Journal of Soil Science**, v. 17, n. 2, 1966.

LAL R. Challenges and opportunities in soil organic matter research. **European Journal of Soil Science**, v. 60, n. 2, p.158-169, 2009.

LEITE, L. F. C.; MENDONÇA, E. S.; NEVES, J. C. L.; MACHADO, P. L. O. A.; GALVÃO, J. C. C. Estoques totais de carbono orgânico e seus compartimentos em argissolo sob floresta e sob milho cultivado com adubação mineral e orgânica. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 27, n. 5, p. 821-832, 2003.

LUCIANO, R. V.; BERTOL, I.; BARBOSA, F. T.; KURTZ, C; FAYAD, J. A. Propriedades físicas e carbono orgânico do solo sob plantio direto comparados à mata natural, num Cambissolo Háplico. **Revista de Ciências Agroveterinárias**, Lages, v. 9, n. 1, p. 09-19, 2010.

LUO, Y.; DURENKAMP, M.; DE NOBILI, M.; LIN, Q.; DEVONSHIRE, B. J.; BROOKES, P. C. Microbial biomass growth, following incorporation of biochars produced at 350 °C or 700 °C, in a silty–clay loam soil of high and low pH. **Soil Biology and Biochemistry**, v. 57, p. 513-523, 2013.

MA, N. N.; ZHANG, L. L.; ZHANG, Y. L.; YANG, L. J.; YU, C. X.; YIN, G. H.; DOANE, T. A.; WU, Z. J.; ZHU, P.; MA, X. Z. Biochar improves soil aggregate stability and water availability in a Mollisol after three years of field application. **PloS one**, v. 11, n. 5, 2016.

MARTINEZ-BALMORI, D.; SPACCINI, R.; AGUIAR, N. O.; NOVOTNY, E. H.; OLIVARES, F. L.; CANELLAS, L. P. Molecular characteristics of humic acids isolated from vermicomposts and their relationship to bioactivity. **Journal of Agricultural and Food Chemistry**, v. 62, p. 11412-11419, 2014.

MEDINA, J.; MONREAL, C.; BAREA, J.M.; ARRIAGADA, C.; FERNANDO, B.; CORNEJO, P. Crop residue stabilization and application to agricultural and degraded soils: a review. **Waste Management**, v. 42, p. 41–54, 2015.

MELO, D. M.; COELHO, E. F.; BORGES, A. L.; PEREIRA, B. L. S.; CAMPOS, M. S. Agronomic performance and soil chemical attributes in a banana tree orchard fertigated with humic substances. **Pesquisa Agropecuária Tropical**, v. 46, n. 4, p. 421-428, 2016.

MUSCOLO, A.; SIDARI, M.; NARDI, S. Humic substance: relationship between structure and activity. Deeper information suggests univocal findings. **Journal of Geochemical Exploration**, v. 129, p. 57-63, 2013.

NEILSEN, G. H., D. NEILSEN, L. C. HERBERT AND E. J. HOGUE. Response of apple to fertigation of N and K under conditions susceptible to the development of K deficiency. **American Society for Horticultural Science**, v. 129, n 1, p. 26-31, 2004.

NOVAK, E.; CARVALHO, L. A.; SANTIAGO, E. F.; PORTILHO, I. I. R. Chemical and microbiological attributes under different soil cover. **CERNE**, v. 23, n. 1, p. 19-30, 2017.

OLIVEIRA, I. A.; CAMPOS, M. C. C.; AQUINO, R. E.; FREITAS, L.; SILVA, D. M. P. Spatial dependence of the aggregate stability and organic matter in a cambisol under sugar cane cultivation. **Revista Caatinga**, Rio Grande do Norte, v. 26, n. 4, p. 1-9, 2013.

OLK, D. C.; DINNES, D. L.; SCORESBY, J. R.; CALLAWAY, C. R.; DARLINGTON, J. W. Humic products in agriculture: potential benefits and research challenges—a review**. Journal of Soils and Sediments**. v. 18, n. 8, p. 2881-2891, 2018.

PERUSI, M. C.; CARVALHO, W. A. Comparação de Métodos para Determinação da Estabilidade de Agregados por Vias Seca e Úmida em Diferentes Sistemas de Uso e Manejo do Solo. **Geociências**, v. 27, p. 197-206, 2008.

PRIMO, D. C.; MENEZES, R. C.; SILVA, T. O. Substâncias húmicas da matéria orgânica do solo: uma revisão de técnicas analíticas e estudos no nordeste brasileiro. **Scientia Plena**, v. 7, n. 5, 2011.

QUEIROZ, G. C. M.; DA SILVA, F. W. A.; PORTELA, J. C.; DE OLIVEIRA, V. N. S.; SANTOS, M. V. Densidade e resistência do solo à penetração de raízes em agroecossistemas no semiárido brasileiro. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, Paraiba, v. 14, n. 4, p. 497-505, 2019.

RESENDE, T. M.; DE MORAES, E. R.; FRANCO, F. O.; ARRUDA, E. M.; ARAÚJO, J. R.; SANTOS, D. da S.; RIBEIRO, B. T. Avaliação física do solo em áreas sob diferentes usos com adição de dejetos animais no bioma cerrado. **Bioscience Journal**, v. 28, n. 1, 2012.

RIBAS, J. R.; VIEIRA, P. R. da C. **Análise Multivariada com o uso do SPSS**. Rio de Janeiro: Editora Ciência Moderna, 2011.

ROSSET, J. S.; LANA, M. C.; PEREIRA, M. G.; SCHIAVO, J. A.; RAMPIM, L.; SARTO, M. V. M. Frações químicas e oxidáveis da matéria orgânica do solo sob diferentes sistemas de manejo, em Latossolo Vermelho. **Pesquisa Agropecuária Brasileira**, Viçosa, v. 51, n. 9, p. 1529-1538, 2016.

ROSCOE, R.; MERCANTE, F. M.; MENDES, I. C.; REIS JUNIOR, F. B.; SANTOS, J. C. F.; HUNGRIA, M. Biomassa microbiana do solo: fração mais ativa da matéria orgânica. In: ROSCOE, R. (ed.). **Dinâmica da matéria orgânica do solo em sistemas conservacionistas**: modelagem matemática e métodos auxiliares. Dourados: Embrapa Agropecuária Oeste, 2006.

SELIM, E.; MOSA, A. A. Fertigation of humic substances improves yield and quality of broccoli and nutrient retention in a sandy soil. **Journal of Plant Nutrition and Soil Science**, Berlin, v. 175, n. 2, p. 273-281, 2012.

SELIM, E. M.; MOSA, A. A.; EL-GHAMRY, A. M. Evaluation of humic substances fertigation through surface and subsurface drip irrigation systems on potato grown under Egyptian sandy soil conditions. **Agricultural water management**, v. 96, n. 8, p. 1218-1222, 2009.

SINGH, B. K.; TATE, K.; THOMAS, N.; ROSS, D.; SINGH, J. Differential effect of afforestation on nitrogen-fixing and denitrifying communities and potential implications for nitrogen cycling. **Soil Biology and Biochemistry**, v. 43, n. 7, p. 1426-1433, 2011.

SOUZA, L. S.; SOUZA, L. D. **Caracterização físico hídrica de solos da área do Centro Nacional de Pesquisa Mandioca e Fruticultura Tropical**. Embrapa Mandioca e Fruticultura, 2001. (Boletim de Pesquisa e Desenvolvimento n° 20).

TEIXEIRA, C. P.; DONAGEMMA, G. K.; FONTANA, A.; TEIXEIRA, W. G. **Manual de métodos de análise de solo**. 3. ed. Brasília: Embrapa, 2017.

VANCE, E. D.; BROOKES, P. C.; JENKINSON, D. S. An extraction method for measuring soil microbial biomass C. **Soil Biology and Biochemistry**, Oxford, v. 19, p. 703-707, 1987.

VASCONCELOS, R. F. B.; CANTALICE. J. R. B.; OLIVEIRA, V. S.; COSTA, Y. D. J.; CAVALCANTE, D. M. Estabilidade de agregados de um Latossolo Amarelo distrocoeso de Tabuleiro costeiro sob diferentes aportes de resíduos orgânicos da cana-de-açúcar. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 34, n. 2, p. 309-316, 2010.

YILMAZ, E. Changes of some soil properties by agricultural processing waste (soybean pulp) amendment. **Journal of Food, Agriculture and Environment**, v. 8, p. 1057-1060, 2010.

WANG, X. J.; JIA, Z. K.; LIANG, L. Y.; YANG, B. P.; DING, R. X.; NIE, J. F.; WANG, J. P. Maize straw effects on soil aggregation and other properties in arid land. **Soil and Tillage Research,** v. 153, p. 131–136, 2015b.

WEI, T.; ZHANG, P.; WANG, K.; DING, R. X.; YANG, B. P.; NIE, J. F.; JIA, Z. K.; HAN, Q. F. Effects of wheat straw incorporation on the availability of soil nutrents and enzyme activities in semiarid areas. **Plos One**, 2015.

ZHANG, L.; ZHOU, J. U. N.; ZHAO, Y. G. U. I.; ZHAI, Y.; WANG, K. A. I.; ALVA, A. K.; PARAMASIVAM, S. Optimal combination of chemical compound fertilizer and humic acid to improve soil and leaf properties, yield and quality of apple (Malus domestica) in the loess plateau of China. **Pakistan Journal of Botany**, v. 45, n. 4, p. 1315-1320, 2013.

ZHENG, J. F.; CHEN, J. H.; PAN, G. X.; LIU, X. Y.; ZHANG, X. H.; LI, L. Q.; BIAN, R. J.; CHENG, K.; ZHENG J. W. Biochar decreased microbial metabolic quotient and shifted community composition four years after a single incorporation in a slightly acid rice paddy from Southwest China. **Environmental Sciences**, v. 571, p. 206-217, 2016.

ZHONG, X. L.; LI, J. T.; LI, X. J.; YE, Y. C.; LIU, S. S.; XU, G. L.; NI, J. Early effect of soil aggregates on enzyme activities in a forest soil with simulated N deposition elevation. **Acta Ecologica Sinica**. v. 35, p. 1422-1433, 2015.

ZANDONADI, D. B., SANTOS, M. P., BUSATO, J. G., PERES, L. E. P., FAÇANHA, A. R. Plant physiology as affected by humified organic matter. **Theoretical and Experimental Plant Physiology**, v. 25, n. 1, p. 13-25, 2013.