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Microbiological properties of soils are sensitive to changes provided by organic cultivation of banana 'BRS Princesa' in the semi-arid region

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ABSTRACT. Soil microbiota has a key role in the dynamics of natural and agro-ecosystems and is sensitive to changes in these environments. This study evaluated changes in the microbiological properties of soils under an organic production system of banana 'BRS Princesa' (*Musa* spp.). The experimental design consisted of completely randomized blocks, with four replications. Treatments consisted of 1) soil cover with green manure and agricultural gypsum at a dose of 2,820 kg ha^{-1}, 2) soil cover with green manure without gypsum application, 3) soil cover with weeds and agricultural gypsum at a dose of 2,820 kg ha^{-1}, 4) soil cover with spontaneous plants without gypsum application, and two controls: 5) soil under native Caatinga and 6) soil under regenerating forest (capoeira). The evaluated properties were β-glucosidase, arylsulfatase, acid phosphatase, fluorescein diacetate hydrolysis activities (FDA), carbon and phosphorus contents in microbial biomass, basal soil respiration, microbial and metabolic quotients, and arbuscular mycorrhizal fungi spore density. Soil samples were collected from the 0–0.20m depth layer in two seasons. No parameter could distinguish the treatments. Spontaneous plants provided conditions equivalent to those under green manure. Agricultural gypsum application also did not influence the microbial biomass and microbiota activity, in the analyzed soil depth. However, β-glucosidase and arylsulfatase activities, the carbon content in microbial biomass, and metabolic and microbial quotients were sensitive to land-use changes and could distinguish areas under organic cultivation from those under native vegetation. Therefore, these properties can be considered good indicators for monitoring the quality of these soils. Furthermore, microbial communities of soils under organic cultivation responded with arylsulfatase activity corresponding to that found in soils under regenerating forest, which may indicate that organic management tends to provide the microbiota with a condition similar to that found under situations that are little disturbing to edaphic living.

Keywords: soil enzymatic activity; bioindicators; microbial biomass; organic fruit growing; microbial; metabolic quotients.

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Introduction

The Northeast region of Brazil has an ideal ecophysiological environment for banana cultivation. The activity has been mainly developed by family farmers, reinforcing its socio-economic importance. The region produced 2.332.671 t bananas in 2019, which corresponds to 34.24% of all national production. The northeastern state of Bahia is the second largest national producer (828.284 t in 2019), surpassed only by São Paulo (1.008.770 t) (Instituto Brasileiro de Geografia e Estatística [IBGE], 2021). Despite the growing demand for agroecological management practices, much of the national banana production still depends on agrochemicals.

In this context, organic cultivation presents itself as an opportunity for several production chain segments. It is guided by principles and knowledge generated by agroecology, and its primary concern is the recovery and maintenance of biological balance. The soil is managed as a living environment in this type of cultivation, wherein the microbiota plays a fundamental role in maintaining its dynamics.

Several researchers have studied cropping system influences on soil biomass and microbial activity. Faria, Melloni and Melloni (2021) observed mean values of microbial biomass between 677.13 and 927.69 μg C g^{-1} C g dry soil, qCO_2 values between 1.79 and 2.35 μg CO_2 μg^{-1} C g dry soil day^{-1}, and basal respiration between 38.29

and 71.16 µg CO_2 g^{-1} dry soil day^{-1} in an area of organic banana cultivation, with no significant difference for forest soils, so that cultural and management practices contributed to good soil quality. Aguiar et al. (2013) found significantly higher biomass carbon values in an area with *Brachiaria* sp. (175.15 mg C kg^{-1} soil) compared to soils under organic banana cultivation (147.70 mg C kg^{-1} soil), which in turn had higher indexes than degraded soils (70.00 mg C kg^{-1} soil). Cavalcante, Silva, Silva, Oliveira and Moreira (2020) identified higher enzymatic activity for β-glycosidase and arylsulfatase in soils under preserved Caatinga biome compared to anthropized soils.

This research aimed to study the sensitivity of microbiological attributes to changes in soils cultivated by banana 'BRS Princesa' submitted to organic management under different vegetation cover and treated or not with agricultural gypsum. We also sought to make inferences about the health of these soils, considering as references an area without human alteration and an area under regenerating forest.

Material and methods

The study was carried out in the experimental area of *Embrapa Mandioca e Fruticultura* in partnership with the company Bioenergia Orgânicos LTDA, in the city of Lençóis, Chapada Diamantina, Bahia State (Brazil). The area is located at 12°36′29.4″ S and 41°21′14.6″ W, with an altitude of 437 m. The local climate is classified as Aw (Tropical Savannah), which is characterized by high annual temperatures, rainy summers, and dry winters (Köppen, 1948). The annual averages of rainfall and temperature in Lençóis are 1,206 mm and 23.9°C, respectively.

The experiment was performed between May 2018 and April 2019. Within this period, total monthly rainfall ranged between 1.8 and 243.6 mm, and temperature averages reached a minimum of 14.65°C and a maximum of 34.78 °C (Figure 1).

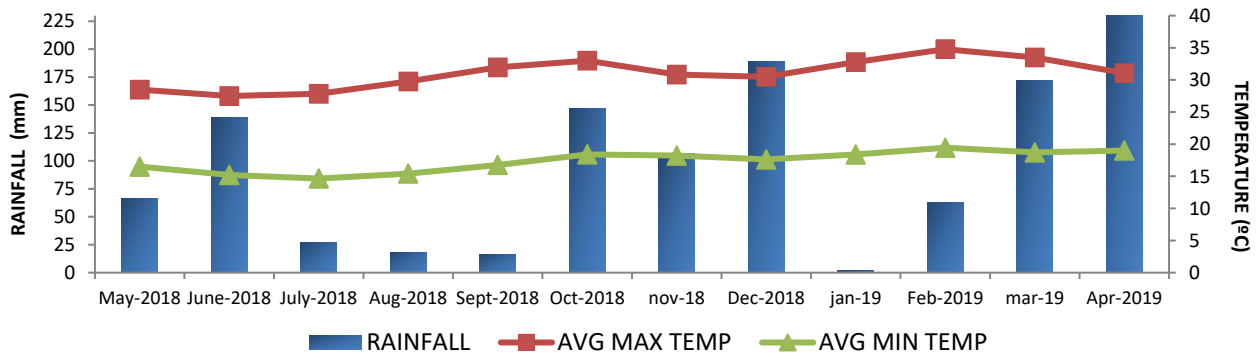

Figure 1. Total monthly rainfall and monthly maximum and minimum temperatures between May 2018 and April 2019.
Data source: INMET – National Institute of Meteorology. Meteorological Database for Teaching and Research – BDMEP, 2019.

The local soil is classified as a clayey dystrophic Red-Yellow Latosol (Oxisol). Table 1 shows its chemical properties from laboratory analyses (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 2017).

Table 1. Chemical properties of soils under forest, scrub vegetation, and organic banana (*Musa* spp.) production systems.

Treatment (1)	pH	P	SB	K	Ca	Mg	Ca+Mg	Al	Na	H+Al	CEC	V
	in H_2O	mg dm^{-3}					cmol dm^{-3}					%
B-SC-G2	5.50	8.00	4.75	0.19	2.38	1.96	4.33	0.20	0.23	8.21	12.96	37.75
B-CC-G2	5.93	18.50	5.72	0.15	2.86	2.61	5.47	0.00	0.12	5.66	11.38	50.75
B-SC-G0	5.75	14.50	5.67	0.15	2.75	2.64	5.39	0.00	0.12	7.53	13.19	43.00
B-CC-G0	5.83	11.25	5.60	0.17	2.55	2.45	5.01	0.08	0.42	6.80	12.39	47.25
Forest	4.28	4.00	0.92	0.19	0.34	0.38	0.72	1.55	0.01	10.18	11.10	8.50
Scrub vegetation	4.60	2.75	2.10	0.08	1.09	0.92	2.01	1.03	0.01	9.52	11.62	16.75

(1) B-SC-G2 (without soil cover and with gypsum application), B-CC-G2 (with soil cover and with gypsum application), B-SC-G0 (without soil cover and without gypsum application), B-CC-G0 (with soil cover and without gypsum application).

The experimental area has been cultivated under an organic system since 2017. All used inputs and practices followed the Normative Instruction No. 46 of October 6, 2011, amended by Normative Instruction N. 17 of June 18, 2014. These norms regulate organic cultivation in Brazil, as well as permitted substances and practices.

The experiment was designed in randomized blocks and arranged in a 6 x 2 factorial scheme, with six treatments: T1) B-SC-G2: soil cover characterized by weed growth and hoeing until the establishment of

the main crop (banana) and gypsum application at a dose of 2,820 kg ha^{-1}; T2) B-CC-G2: soil cover characterized by successive sowing and cutting of several plants used as green manures [jack bean (*Canavalia ensiformis* L. DC.), velvet bean (*Mucuna pruriens* L. DC.), sorghum (*Sorghum bicolor* L. Moench), and pearl millet (*Pennisetum glaucum* L. R. Br.) at equal proportions] until the establishment of the main crop (banana) and gypsum application at a dose of 2,820 kg ha^{-1}; T3) B-SC-G0: soil cover characterized by weed growth and hoeing until the establishment of the main crop (banana) and without gypsum application; T4) B-CC-G0: soil cover characterized by successive sowing and cutting of several plants used as green manure [jack bean (*Canavalia ensiformis* L. DC.), velvet bean (*Mucuna pruriens* L. DC.), sorghum (*Sorghum bicolor* L. Moench), and pearl millet (*Pennisetum glaucum* L. R. Br.) at equal proportions] until the establishment of the main crop (banana) and without gypsum application; and T5 and T6) areas under native forest and scrub vegetation (native vegetation in regeneration), respectively, both surrounding the banana cultivation areas and forming a vegetal cord, in addition to serving as controls. The two collection times were September 2018 and April 2019, with four replicates each. Each plot consisted of 18 plants, spaced at 2 x 2 m, and with an area of 62.5 m^2.

Four soil samples were collected from each treatment, taken from the 0–0.20 m depth layer. The samples were placed in plastic bags and sent to the Laboratory of Soil Microbiology and Organic Residues at *Embrapa Mandioca e Fruticultura*, in Cruz das Almas – BA. Therein, they were sieved through a 2-mm mesh screen and kept at about 4°C in a refrigerator until microbiological analysis. Soil moisture values were determined by drying about 10 g of each sample in an oven at 105°C for 24 hours.

The following microbiological properties were evaluated: basal soil respiration (C-CO_2) by CO_2 emission records using a LI-COR (LI-8100A, Lincoln, NE, USA) device equipped with an infrared gas analyzer (Infra-Red Gas Analyzer-IRGA); microbial biomass carbon (MBC) by the fumigation-extraction method (Brookes, Landman, Pruden, & Jenkinson, 1985; Vance, Brookes, & Jenkinson, 1987), with C quantified by oxidation with potassium permanganate (Bartlet & Ross, 1988) and reading by the colorimetric method; microbial biomass phosphorus (Pmic) by the fumigation-extraction method adapted from Brookes, Powlson and Jenkinson (1982) and Murphy and Rilley (1962); activity of the enzymes β-glucosidase (βGLUC), arylsulfatase (ARYS), and acid phosphatase (APH), according to Tabatabai (1994), wherein soil samples were incubated in the presence of specific substrates (p-nitrophenyl-β-D-glucopyranoside, p-nitrophenyl-sulphate, and p-nitrophenyl phosphate, respectively) for 1 hour at 37°C, followed by colorimetric determination of the p-nitrophenol concentration released by the enzymes. Fluorescein diacetate hydrolysis activity (FDA) was determined by the method of Schnurer and Rosswall (1982) adapted by Costa and Godoi (2002). Spore density of arbuscular mycorrhizal fungi (AMF) was determined by wet sieving (Gerdemann & Nicolson, 1963), centrifugation in sucrose (Jenkins, 1964), and count under an optical microscope.

The metabolic quotient (qCO_2) was determined as the ratio between C-CO_2 and MBC, while the microbial quotient (qMic) was determined by the ratio between MBC and total organic carbon (TOC).

Before the analysis of variance (ANOVA), the normality of errors was verified by the Shapiro-Wilk test, whereas the homogeneity of variances was verified by Bartlett's test. The data were transformed for variables that did not meet the normality of errors and/or homogeneity of variances. The original and/or transformed data were subjected to ANOVA in a 6 × 2 factorial scheme (land use × sampling time), and the means were compared by the Scott-Knott test at a 5% probability using R software version 4.0.1 (R Core Team, 2020). The data were also submitted to multivariate principal component (PCA) and clustering analyses by the Euclidean distance as a dissimilarity measure and the UPGMA clustering method (Unweighted Pair Group Method with Arithmetic Mean) using R software version 4.0.1 (R Core Team, 2020).

Results and discussion

No significant interaction was observed between sampling times and treatments for arylsulfatase (ARYS), β-glucosidase (β-GLUC), acid phosphatase (APH), and fluorescein diacetate hydrolysis activities (FDA). Thus, the factors of land use and sampling time were analyzed separately and without any splitting (Tables 2 and 3).

The activities of β-GLUC, ARYS, APH, and FDA were higher in soil samples collected in 2018 (Table 2). It may be associated with the low rainfall in September 2018 (16 mm). Native microorganisms producing these enzymes are adapted to environments with severe conditions and selected to express their activity under situations that would be limiting to another microorganism, such as exposure to high temperatures, solar radiation, and low water availability.

Table 2. β-glucosidase (β-GLUC), arylsulfatase (ARYS), acid phosphatase (APH), and fluorescein diacetate hydrolysis activities (FDA) in soils under organic banana (*Musa* spp.) cultivation, scrub vegetation, and forest. Lençóis, BA, Brazil. 2018 and 2019.

Sampling time	β-GLUC	ARYS	APH	FDA
	(μg p-nitrophenol g^{-1} soil h^{-1})			(2)
2018	51.90a	41.91a	847.17a	466.02a
2019	29.96b	26.68b	455.88b	191.23b

(1) Means followed by the same letter in the column do not differ from each other by the Scott Knott test at a 5% probability. (2) μg fluorescein g^{-1} dry soil h^{-1}

The activity of β-GLUC was higher in soils under forest and scrub vegetation than under organic banana cultivation (Table 3). β-glucosidases are enzymes that participate in the carbon cycle in the hydrolysis of cellobiose, which is a disaccharide of rapid decomposition in the soil, corresponding to the final cellulose decomposition stage. These enzymes also hydrolyze some glucose-soluble oligosaccharides, releasing an energy source for microorganisms (Doni, Macci, Chen, Masciandaro, & Ceccanti, 2012). Higher activity of these enzymes is usually found in less anthropized soils. Lisboa, Vargas, Silveira, Martins and Selbach (2012) observed enzymatic activity of β-GLUC, ARYS, and lower APH in conventional planting, while natural fields and no-tillage areas tended to show similar results. These authors attributed such findings to the ability of no-tillage to preserve the original soil quality.

Cavalcante et al. (2020) compared enzymatic activity in soils under preserved Caatinga biome and anthropized areas and verified that anthropogenic action provides a reduction in the enzymatic activity of β-GLUC and ARYS.

Table 3. β-glucosidase (β-GLUC), arylsulfatase (ARYS), acid phosphatase (APH), and fluorescein diacetate hydrolysis activities (FDA) in soils under forest, scrub vegetation, and organic cultivation of banana 'BRS Princesa' (*Musa* spp.) on the farm Ceral. Lençóis, BA, Brazil.

Treatment	β-GLUC	ARYS	APH	FDA
	μg *p*- nitrophenol g^{-1} soil h^{-1}			(3)
B-SC-G2	29.84b	38.40b	556.84b	350.92a
B-CC-G2	29.98b	34.55b	702.24a	294.09a
B-SC-G0	29.70b	35.02b	760.40a	294.08a
B-CC-G0	33.48b	38.67b	568.52b	297.74a
Forest	43.70a	58.01a	509.47b	359.29a
Scrub vegetation	39.05a	40.93b	811.69a	375.62a
CV (%)	21.30	6.87	25.36	27.98

*Original data transformed into log(x). (1) Means followed by the same letter in the column do not differ from each other by the Scott Knott test at a 5% probability. (2) B-SC-G2 (without soil cover and with gypsum application), B-CC-G2 (with soil cover and with gypsum application), B-SC-G0 (without soil cover and without gypsum application), B-CC-G0 (with soil cover and without gypsum application). (3) μg fluorescein. g^{-1} dry $soil^{-1}$ h^{-1}.

The β-GLUC activity could not distinguish forest and regenerating forest, suggesting their closer characteristics, and distancing them from tilled soils. The enzymatic activity of β-GLUC, ARYS, and FDA could not indicate differences among the soils under different organic banana cultivations. They were characterized by the application or not of agricultural gypsum and different soil covers composed of natural vegetation or green manure.

Evangelista, Partelli, Ferreira and Correchel (2012) observed that cultivation systems under organic management and without soil tillage have higher levels of β-GLUC activity, even higher than remaining Cerrado soils at a depth of 0.00–0.10 m. The authors attributed these results to the addition of organic material from organic fertilization and the deposition of straw from successive sugarcane harvests, as β-glucosidase acts in the final step of cellulose decomposition.

However, in the present study, the organic management of banana areas implemented in 2017 promoted, until the time of soil collections, no overcoming of the activity of this enzyme relative to areas of forest and forest in regeneration. A relevant consideration is that the collections were performed at a depth of 0.0–0.20 m and some studies have suggested that the discriminatory character of the microbiota tends to decrease at soil depths below 0.00–0.10 m.

Yada et al. (2015) highlighted that not all organic S is subject to hydrolysis by ARYS but only that in the sulfate ester form; therefore, only changes in this form would affect the activity of this enzyme. Perhaps that is why ARYS activity was not influenced by the application of agricultural gypsum.

The ARYS activity was higher in areas under forest, differing from the other areas and bringing soils under organic cultivation closer to areas under regeneration (scrub vegetation). Marcuzzo, Araújo, Rorato and Machado (2014) evaluated the ecological restoration in two areas and observed higher activity of ARYS in forest soils than in areas under revegetation areas, which means that this enzyme is deemed a good indicator of ecological restoration.

Areas under forest had the lowest rates for APH activity. According to Gatiboni, Kaminski, Rheinheimer and Brunetto (2008), areas under forest usually have large amounts of organic C and organic P in soil microbial biomass, in addition to low inorganic P availability. Thus, these conditions could be indicators of a higher APH activity in these soils. Such behavior was not observed in our study, but it is known that APH is an indicator influenced by liming or fertilization, which interferes with the reliability of results.

Analyses of the potential of the enzymatic activity of β-GLU and ARYS as soil quality bioindicators have been validated by *EMBRAPA Cerrados*, which released a technology named BioAS – Bioanalysis of Soils, which is currently available only for annual crop conditions in the Brazilian Cerrado (Mendes et al., 2021). These enzymes were selected because they are easy to analyze and have critical levels already established in Interpretation Tables for the Cerrado, in addition to being of low cost and showing high correlation with other attributes, among other factors (Mendes et al., 2021). This innovation reinforces the importance of defining sensitive attributes for other Brazilian edaphoclimatic conditions and its multitude of existing crops.

No significant interaction effect was found between land use and sampling time. Therefore, these factors act independently on organic matter (OM), microbial biomass carbon (MBC), and their derived indexes, qCO2, and qMic. In this sense, the factors were analyzed in isolation and without further development (Tables 4 and 5).

Table 4. Organic matter (OM), microbial biomass carbon (MBC), metabolic quotient (qCO2), and microbial quotient (qMic) in soils under forest, scrub vegetation, and organic banana (*Musa* spp.) cultivation. Lençóis, BA. 2018 and 2019.

Sampling time	OM	MBC	qCO_2*	qMic
	g kg^{-1}	mg kg^{-1}	mg CO_2 mg^{-1} MBC d^{-1}	%
2018	23.52a	109.81a	0.35b	0.49a
2019	23.99a	79.69b	0.63a	0.35b

*Original data transformed into log(x) +1. (1) Means followed by the same letter in the column do not differ from each other by the Scott. Knott test at 5% probability.

Higher MBC and qMic and lower qCO_2 contents were found in samples collected in 2018 compared to those from 2019 (Table 4). Higher qCO_2 indices indicate that higher levels of carbon dioxide were lost to the atmosphere, no longer being incorporated into biomass (Alves, Campos, Elias Neto, Matsuoka, & Loureiro, 2011). This attribute is widely used to detect stressful conditions for microbial biomass. Less carbon is lost through respiration as it becomes more efficient in using ecosystem resources and higher proportions are attached to microbial tissues (Cunha et al., 2011).

April 2019 was characterized by rainfall above the local average (243.6 mm). It may have represented a limiting condition to the microbiota of Caatinga soils, which are ecosystems subjected to natural water scarcity.

Still, the lowest qCO_2 values were observed in soils under forest and scrub vegetation, differing from those under organic banana cultivation, whose values were the highest (Table 5). According to Ferreira, Wendland and Didonet (2011), low qCO_2 values reflect a more stable environment or closer to its equilibrium state.

Table 5. Organic matter content (OM), microbial biomass carbon (MBC), metabolic quotient (qCO2), and microbial quotient (qMic) in soils under forest, scrub vegetation, and organic banana 'BRS Princesa' (*Musa* spp.) cultivation. Lençóis, BA, Brazil. 2018 and 2019.

Treatment	OM	MBC	qCO_2*	qMic
	g kg^{-1}	mg kg^{-1}	mg C-CO_2 mg^{-1} MBC d^{-1}	%
B-SC-G2	24.78a	71.14b	0.67a	0.29c
B-CC-G2	21.52a	67.89b	0.60a	0.32c
B-SC-G0	26.47a	81.72b	0.49a	0.32c
B-CC-G0	23.85a	67.48b	0.70a	0.30c
Forest	20.10a	153.48a	0.19c	0.78a
Scrub vegetarion	25.83a	126.76a	0.29b	0.51b
CV (%)	21.11	28.39	26.96	31.34

*Original data transformed into log(x) +1. (1) Means followed by the same letter in the column do not differ from each other by the Scott Knott test at a 5% probability. (2) B-SC-G2 (without soil cover and with gypsum application), B-CC-G2 (with soil cover and with gypsum application), B-SC-G0 (without soil cover and without gypsum application), B-CC-G0 (with soil cover and without gypsum application).

OM contents did not differ among the evaluated land uses (Table 5). Likewise, Falcão, Lacerda, Mendes, Leão and Carmo (2013) evaluated OM in a more superficial layer (0.00–0.10m) grown with strawberries and under conventional and organic conditions and observed no differences. Overall, OM content changes occur in the medium or long term, requiring a longer time to be quantified (Carneiro, Souza, Reis, Pereira, &

Azevedo, 2009). Another explanation to be considered is that organic matter contributions to cropping systems may have allowed OM contents equivalent to those of reference areas: forest and scrub vegetation.

Soils under forest and scrub vegetation showed higher MBC contents, with values between 153.3.48 and 126.76 mg kg^{-1}, respectively, differing from areas under organic banana cultivation (67.48 to 81.72 mg kg^{-1}). This result can be attributed to the species diversity in natural environments, which results in increased plant material deposition and oxidizable organic substrates of varied composition in the litter, favoring C immobilization by microbial biomass (Cunha, Stone, Ferreira, Didonet, & Moreira, 2012). This result corroborates those of Ferreira, Stone and Martin-Didonet (2017), who analyzed microbial population and activity under an agroecological production system and observed higher averages of MBC in soil under native vegetation at all sampling times, except at flowering.

The forest areas also presented higher averages of qMic, followed by scrub vegetation. This area, in turn, had averages significantly higher than those under organic banana cultivation (Table 5). The parameter qMic expresses the amount of soil organic C immobilized in microbial biomass (Duarte et al., 2014). Therefore, the results demonstrate microbial efficiency in C immobilization in the reference areas, where the highest amount of biomass is sustained per unit of organic carbon.

Also, no significant difference was observed for qCO_2 among soils under organic banana cultivation. It only reflected the increasing scale of the environmental balance among the soils under study (Table 5).

Microbial biomass metabolic activity, expressed by basal soil respiration (C-CO_2), varied among land uses, management systems, and sampling times (Table 6). The lowest values were recorded in forest soils in both sampling periods, not differing from some areas under organic cultivation. Duarte et al. (2014) stated that higher microbial respiration values can occur in more disturbed or highly productive soils. Therefore, this property must be assessed together with other indicators to enable proper understanding and interpretation of the facts.

Table 6. Basal soil respiration (C-CO2), microbial biomass phosphorus (Pmic), and spore density of arbuscular mycorrhizal fungi (AMF) in soils under forest, scrub vegetation, and organic banana 'BRS Princesa' (*Musa* spp.) cultivation. Lençóis, BA, Brazil. 2018 and 2019.

Treatment	C-CO_2 mg kg^{-1} d^{-1}		Pmic mg kg^{-1} d^{-1}		AMF absolute numbers /100 g soil	
	2018	2019	2018	2019	2018	2019
B-SC-G2	29.48bA	30.94bA	17.12bA	20.37aA	57.00bB	132.25aA
B-CC-G2	43.75aA	28.28bB	10.06bB	27.51aA	89.25aB	177.25aA
B-SC-G0	32.43bB	43.17aA	15.76bA	14.47aA	101.25aA	162.25aA
B-CC-G0	38.99aA	44.51aA	18.39bA	10.61aA	48.50bB	192.87aA
Forest	27.74bA	27.88bA	10.55bB	23.94aA	18.75bA	34.75bA
Scrub vegetation	29.88bA	36.38aA	47.57aA	16.26aB	41.50bA	46.75bA
CV (%)	19.08		46.56		46.57	

(1) Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5% probability. (2) B-SC-G2 (without soil cover and with gypsum application), B-CC-G2 (with soil cover and with gypsum application), B-SC-G0 (without soil cover and without gypsum application), B-CC-G0 (with soil cover and without gypsum application).

The evaluated treatments could not be differentiated in terms of Pmic content, as this variable showed no variation pattern. Gatiboni et al. (2008) observed that soils with low available P content, such as those in our study, have no microbial biomass capable of immobilizing large amounts of this element.

In addition to Pmic, biological transformations of P in the soil by microorganisms include mechanisms that range from promoting lateral root and root hair growth to effective metabolic process stimuli in P solubilization and mineralization from poorly available forms, until APH production, and mycorrhizal association interferences (Rodrigues, Pavinato, Withers, Teles, & Herrera, 2015).

Lower mycorrhizal fungi spore densities were found for both sampling times in soils under forest and scrub vegetation (Table 6). Ferreira, Carneiro and Saggin Junior (2012) emphasized that AMF spore production is a perpetuation mechanism of the species and is stimulated when plants and fungi are subjected to some stress. These authors observed an increase in spore density in areas subjected to strong water stress at the sampling time. Mergulhão et al. (2014) also stated that mycorrhizal symbiosis is a plant strategy to overcome biotic and abiotic stresses, increasing spore density under adverse conditions.

The Principal Component Analysis (PCA) allowed identifying the most relevant properties to discriminate the sampled areas. Among the ten analyzed microbiological parameters, together with OM,

the two principal components that had the greatest influence on the results in 2018 were extracted for explaining 84.17% of the total data variability (Figure 2a).

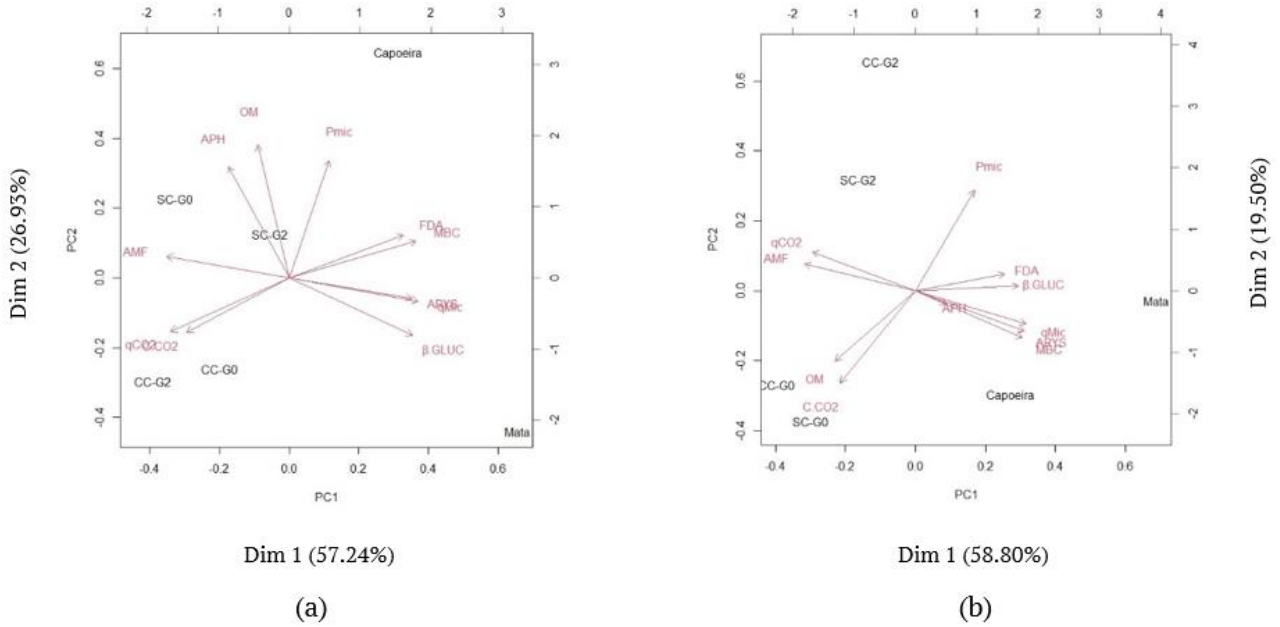

Figure 2. Weights of ten microbiological soil properties and total organic carbon (TOC) in the first two principal components. Lençóis, BA, Brazil. 2018 (a) and 2019 (b); SC-G2 (without soil cover and with gypsum application), CC-G2 (with soil cover and with gypsum application), SC-G0 (without soil cover and without gypsum application), CC-G0 (with soil cover and without gypsum application); β-glucosidase (β-GLUC), arylsulfatase (ARYS), acid phosphatase (APH), and fluorescein diacetate hydrolysis activities (FDA), organic matter content (OM), microbial biomass carbon (MBC), metabolic quotient (*q*CO2), and microbial quotient (qMic); basal soil respiration (C-CO2), microbial biomass phosphorus (Pmic), and spore density of arbuscular mycorrhizal fungi (AMF).

Principal component (PC) 1 explained 57.24% of the data variability in 2018 and presented a strong positive correlation with qMic, MBC, β-GLUC, and ARYS, in that order, as well as a strong negative correlation with AMF and qCO_2 (Figure 2a). In 2019, the properties related to soil biological quality explained 78.30% of the total data variability in the two PCs, with PC 1 being efficient in explaining 58.8% of this variation, which shows a strong positive correlation with qMic, ARYS, MBC, and β-GLUC, in that order, and a strong negative correlation with AMF and qCO_2 (Figure 2b).

Importantly, the properties that had high factorial weights indicate which of them have the greater discriminatory capacity in clustering by the PC in question (Santi et al., 2012).

PCA confirmed the enzymatic activity of β-GLUC and ARYS, as well as MBC, qMic, qCO_2, and AMF, as sensitive indicators to changes in the environment by cultivation. In this interpretation, only PC 1 of each sampling time was considered, as it explained nearly 60% of the data variation in each period, indicating the most significant properties to distinguish the environments.

Figures 2a and 2b show areas under native vegetation far from those under organic cultivation positioned on the right quadrants. One can note that soils under scrub and forest in 2018 are not grouped with the cropping systems, which is an indication of the particularity of these soils regarding the analyzed properties.

Multivariate cluster analysis enabled us to visualize the approximation between each land use as a function of the similarity between them. Based on this, Figure 3 shows the formation of five clusters.

The forest areas in both sampling times and scrub vegetation in 2018 formed distinct clusters. The other clusters distinguished the soils under organic cultivation at different sampling times with scrub vegetation in 2019, forming a cluster concomitant with banana cultivation in 2018 (Figure 3). September 2018 showed climate characteristics closer to those commonly found in semi-arid environments.

The clusters showed no significant difference among the treatments under organic banana cultivation but between them and areas under native vegetation (forest and scrub), corroborating the test of means.

Our results allow access to information on the biology of soils cultivated with banana 'BRS Princesa' in the semi-arid region of Bahia, enabling the monitoring of their quality over time.

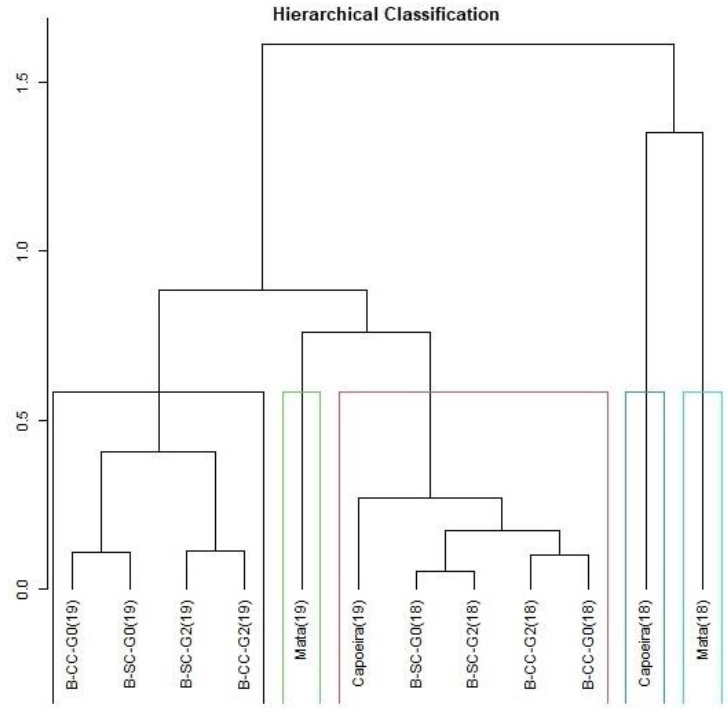

Figure 3. Dendrogram based on Mahalanobis distance and UPGMA clustering method for 10 microbiological properties and soil organic matter. Lençóis, BA, Brazil. 2018 (18) and 2019 (19).

Conclusion

Organic banana 'BRS Princesa' cultivation alters biomass, microbial activity, and spore density of mycorrhizal fungi compared to native forest and regenerating areas.

The enzymatic activity of β-glucosidase and arylsulfatase, microbial biomass carbon, metabolic and microbial quotients, and spore density of mycorrhizal fungi are sensitive indicators regarding the anthropogenic interference on soils under organic cultivation.

Agricultural gypsum application does not promote significant effects on microbial indicators within the 0.00–0.20 m depth layer of a Red-Yellow Latosol under organic banana 'BRS Princesa' cultivation.

Spontaneous plants can be used as soil covers.

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