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Chemical and microbiological attributes of sandy soil fertilized with crushed green coconut shell[1]

Atributos químicos e microbiológicos de um solo arenoso adubado com casca triturada de coco verde

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ABSTRACT - The objective of this work was to evaluate the chemical composition of crushed green coconut shell and its effects on soil attributes. The treatments consisted of areas that received the residue and presented differences in the reaction time with the soil: 1 (T1); 12 (T2); 36 (T3) and 72 months (T4) and another area, in which the residue was not applied (T5). Samples of residues remaining on the soil surface were collected to evaluate the chemical composition and soils for chemical analysis, microbial activity, and arbuscular mycorrhizal fungi. Nutrients and sodium concentrations remained the same over time, providing, in order of magnitude, the contribution of organic C > K > N > Ca > Mg > Na > P > S > Fe > Mn > Zn > Cu to the soil. Over the periods evaluated, there were increases in the availability of elements, such as N, P, K and Na, and increases in the sum of base and cation exchange capacity of the soil. During the treatment with the longest period evaluated, there were increases in microbial biomass activity, measured by edaphic respiration and by metabolic and mineralization quotients. As time progressed, there were variations in communities of arbuscular mycorrhizal fungi, but this did not affect the diversity of fungal species. The most prevalent spore morphotypes belonged to *Acaulospora laevis, A. scrobiculata* and *Claroideoglomus etunicatum*. The application of 100 t ha^{-1} of crushed green coconut shell promotes changes in the chemical and microbiological soil attributes, especially in the first months of the application of the residue. Reapplying residue 36 months after the first application is recommended.

Key words: *Cocos nucifera*. Lignocellulosic residue. Agroindustrial waste. Soil quality.

RESUMO - O objetivo deste trabalho foi avaliar a composição química da casca de coco verde triturada e seus efeitos nos atributos do solo. Os tratamentos consistiram em áreas que receberam o resíduo e apresentaram diferenças no tempo de reação com o solo: 1 (T1); 12 (T2); 36 (T3) e 72 meses (T4) e outra área, onde não foi aplicado o resíduo (T5). Amostras de resíduos remanescentes na superfície do solo foram coletadas para avaliação da composição química e de solos para análise química, atividade microbiana e de fungos micorrízicos arbusculares. Os teores de nutrientes e sódio permaneceram as mesmas ao longo do tempo, fornecendo, em ordem de magnitude, a contribuição de C > K > N > Ca > Mg > Na > P > S > Fe > Mn > Zn > Cu para o solo. Nos períodos avaliados houve aumento na disponibilidade de elementos, como N, P, K e Na, e aumento na soma de bases e na capacidade de troca catiônica do solo. Durante o período mais longo avaliado houve aumento da atividade da biomassa microbiana, medida pela respiração edáfica e pelos quocientes metabólico e de mineralização. Com o passar do tempo houve variações nas comunidades de fungos micorrízicos arbusculares, mas isso não afetou a diversidade de espécies de fungos. Os morfotipos de esporos prevalentes foram de *Acaulospora laevis, A. scrobiculata e Claroideoglomus etunicatum*. A aplicação de 100 t ha^{-1} de casca de coco verde triturada promove mudanças nos atributos químicos e microbiológicos do solo, principalmente nos primeiros meses de aplicação do resíduo. Sugere-se reaplicar o resíduo 36 meses após a aplicação.

Palavras-chave: *Cocos nucifera*. Resíduo lignocelulósico. Resíduos agroindustriais. Qualidade do solo.

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INTRODUCTION

The coconut palm tree (*Cocus nucifera* L.) is a monocotyledon belonging to the *Arecaceae* family, and is widely disseminated throughout Asia, Africa, Oceania, Central America and Caribbean, and South America (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2018). Within Brazil, the northeast is responsible for 70% of coconut production. The main areas of production are to be found on the coastal strips of the states of Bahia, Ceará and Rio Grande do Norte (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2018).

For the cultivation of coconut palm trees in that tropical coastal region it is necessary to take into consideration the nutritional requirements of the trees, as well as the morphoclimatic aspects related to natural resources and the soil. The nutritional requirements of the adult coconut palm tree are in the following decreasing order: K > N > Ca > Mg > P (MALHOTRA *et al*., 2017). Also, Saldanha *et al*. (2017) highlight the main nutritional limitations as K > P > Ca > Fe > N among other elements in hybrid coconut palm trees cultivated throughout the Brazilian northeast.

Other, equally important, factors involve vegetative and reproductive aspects, such as the age of the coconut palm trees and climatic conditions, particularly in semi-arid regions where there is an uneven distribution of rainfall, leading to the atrophy of bunches of fruits in dry periods (CÂMARA *et al*., 2019). In established plantations, the accumulation of residual organic matter from coconut palm trees, and other organic residues may significantly affect the rhizospheric soil microbiota (MALHOTRA *et al*., 2017). It should be noted that the microorganisms act on the cycles of carbon and other elements, affecting the concentrations of nutrients in the soil (SCHIMEL; SCHAEFFER, 2012) which are essential to plant growth.

Making use of the coconut shells deposited on the outskirts of towns and cities along the coast and in places set aside for coconut agro-industry residue would be desirable, enabling gas emissions (including CH_4) to be reduced (NUNES *et al*., 2020). Another possibility involves the use of the lignocellulosic residue as organic fertilizer. There has been, however, little information about the decomposition process of green coconut shells and the effect of this fertilizer on the quality of the soil. Considering the possibility of using the crushed green coconut shell for application between the rows of the coconut palm tree plantation, it can be hypothesized that the reaction time of the residue with the soil will result in changes in its chemical composition and, in turn, changes in the chemical and microbiological attributes of the soil.

This work aimed to evaluate the chemical attributes of crushed green coconut shell used in plantations for varying amounts of time and the effects of this residue on the chemical and biological attributes of the soil. The results are encouraging and should lead to the use of coconut residue in cultivated areas near the coconut agroindustry, seeking a more sustainable food production in the coastal ecosystems.

MATERIAL AND METHODS

The study was carried out on an irrigated dwarf-coconut palm tree plantation, which was subjected to different fertilization treatments using crushed green coconut shell. The plantation was located beside the RN 263 highway, and the farm buildings were set at 5°27'34" S, 35°22'7" W, in the Municipality of Maxaranguape, Rio Grande do Norte (Brazil). The climate of the region, according to the Köppen classification system, is As (tropical with dry summers) (ÁLVARES *et al*., 2013), where the air temperature ranges from 25 to 30 °C and rainfall reaches 1,300 mm per year. A trench was dug in the central part of the plantation in order to analyze the surface horizons, in which it was classified as Typic Quartzipsamment (Table 1).

Five areas of approximately two hectares each were selected, four of which received crushed green coconut shell on the soil surface between the rows of the orchard, at a dose of 100 t ha^{-1} (equivalent to 10 kg m^{-2} dry basis) and applied only once, shortly after planting the dwarf coconut palm tree. Those areas that received the residue showed differences in the reaction time of the residue with the soil: 1 (T1); 12 (T2); 36 (T3) and 72 months (T4). Another area, in which the residue was not applied between the rows, was used as a control (T5). The coconut palm trees were planted in 2012 (T4); 2015 (T3); 2017 (T2) and 2018 (T1), in triangular spacing of 7.5 m by 7.5 m (205 plants per hectare). The design adopted was randomized blocks, with six replicates of each treatment. The residue applied to the areas was obtained at the coconut water processing plant, located inside the farm.

Samples of the residue were collected in 2018, from the central areas between the rows of coconut palm trees, using a circular arc (0.132 m^2), to measure the biomass of the residue (kg m^{-2}). Immediately afterwards, representative samples of residue were dried in a forced air circulation oven at 65 ºC and passed through a Wiley Mill with a 2 mm mesh, for a chemical analysis of the residue.

The soil samples were collected at a depth of 0-10 cm from the same areas between the rows of coconut palm trees. Each sample was composed of ten or more simple samples taken from each experimental unit. Once collected, the soil of the samples was broken up

Table 1 - Morphological description of the horizons and granulometric, chemical and biological attributes of Typic Quartzipsamment in the orchard with dwarf coconut trees (Maxaranguape, RN)

Horizons	Depths (cm)	Morphological description								
		Munsell chart color	Observation							
Ap1	0 – 9	Strong-Brown (7.5YR 4/6)	Sand, non-plastic and non-sticky, smooth and clear transition.							
Ap2	9 – 17	Yellow-Red (10YR 5/6)	Sand, non-plastic and non-sticky, smooth and gradual transition.							
Ap3	17 – 42	Yellow-Red (10YR 5/8)	Sand, non-plastic and non-sticky, smooth and gradual transition.							
C1	42 – 83	Strong-Brown (7.5YR 5/8)	Sand, non-plastic and non-sticky, flat and diffuse transition.							
C2	83 – 139	Strong-Brown (7.5YR 5/8)	Sand-free, non-plastic and non-sticky, flat and diffuse transition.							
C3	139 – 200+	Strong-Brown (7.5YR 5/8)	Sandy, not plastic and not sticky.							
		Granulometry (g kg^{-1})								
		Sand			Silt			Clay		
Ap1	0 – 9	940			26			34		
Ap2	9 – 17	941			21			38		
Ap3	17 – 42	921			13			66		
C1	42 – 83	908			22			70		
C2	83 – 139	888			29			83		
C3	139 – 200+	865			28			107		
		pH	Sorption complex ($cmol_c$ kg^{-1})					EC (dS m^{-1})	P (mg kg^{-1})	SOM (g kg^{-1})
			Ca^{2+}	Mg^{2+}	K^+	Na^+	H+Al			
Ap1	0 – 9	6.6	0.93	0.67	0.02	0.00	0.66	0.25	4	9
Ap2	9 – 17	7.1	0.93	0.67	0.02	0.00	0.00	0.14	2	4
Ap3	17 – 42	6.5	0.62	0.46	0.01	0.00	0.50	0.12	1	2
C1	42 – 83	5.6	0.28	0.22	0.01	0.00	0.99	0.14	2	2
C2	83 – 139	5.6	0.09	0.09	0.01	0.00	0.83	0.06	2	3
C3	139 – 200+	5.4	0.07	0.08	0.01	0.00	0.66	0.12	7	2
		Basal soil respiration			AM fungi			Coconut tree root system		
		(mg C-CO_2 kg^{-1} day^{-1})			(spores 50 g^{-1} soil)					
Ap1	0 – 9	11.53			76			Roots with different sizes		
Ap2	9 – 17	10.69			38			Common thin and medium roots		
Ap3	17 – 42	7.54			8			Few medium and rare thick roots		
C1	42 – 83	4.79			4			Few medium and rare thick roots		
C2	83 – 139	4.81			Undetected			Rare medium and rare thick roots		
C3	139 – 200+	4.73			Undetected			Rare medium and rare thick roots		

and passed through a sieve with a 2 mm mesh and dried in a forced air circulation oven at 45 °C, for chemical analysis. Other fractions of wet soil were sieved (2 mm) and kept refrigerated (5 ºC) until chemical and microbiological analyses had been carried out.

One fraction of crushed green coconut shell was used to determine total organic carbon (TOC) content and other nutrients, as set out by Silva (2009). The contents of macronutrients (P, K, Ca, Mg and S), micronutrients (Cu, Fe, Mn and Zn) and Na were measured using extracts with organic residue digested in a solution of nitric-perchloric (3:1 v/v), and the quantification was made in an inductively coupled plasma optical emission spectrometer (Agilent 5100, Agilent). In addition, the N content was determined using the dry combustion method (NDA 701, Velp Scientifica).

Active acidity (pH in H_2O), potential acidity (H+Al) and total organic carbon (TOC), plus macro- and micronutrients were determined according to Silva (2009). The extraction process using Mehlich-1 solution was used in order to determine the contents of available P, K^+, Na^+, Cu^{2+}, Fe^{2+}, Mn^{2+} and Zn^{2+}, while Ca^{2+}, Mg^{2+} and Al^{3+} were extracted from the soil using 1 M solution of KCl. The cation exchange capacity (CEC) of the soil was calculated by the sum of exchangeable cations and potential acidity. The total N content in the soil was determined by the dry combustion method (NDA 701, Velp Scientifica).

Microbial biomass carbon (MBC) was measured using the fumigation-extraction method (DE-POLLI; GUERRA, 1997), and basal soil respiration (BSR) was measured according to Silva, Azevedo and De-Polli (2007). These properties and TOC enabled the metabolic quotient (qCO_2, rate between BSR and MBC), the microbial quotient (qMic, rate between MBC and TOC) and the mineralization quotient (qMin, rate between BSR and TOC) of the topsoil to be measured. The arbuscular mycorrhizal (AM) fungi spores were extracted from the soil, using the wet sieve technique, followed by sucrose gradient centrifugation (SIEVERDING, 1991). Fungal spore suspension was observed using a stereomicroscope (up to 100x) for the counting and separation of spores from AM fungi in the soil. Morphotypes of fungal spores were mounted on glass slides using the fixers PVLG (polyvinyl alcohol-lactic glycerol) and PVLG + Melzer for the identification of species, making use of INVAM and the descriptions of fungal species.

The attributes of the remaining coconut shell residue and those of the soil were subjected to variance analysis in randomized blocks, and the averages of the treatments were compared using the Tukey test (p=0.05). All analyses were carried out using the PROC GLM model (General Linear Model procedure) statistical analysis software - SAS, version 9.3 (SAS Institute Inc.). Information from the sampling units was also subjected to Pearson's multivariate Principal Component Analysis (PCA), and Agglomerative Hierarchical Clustering (AHC) by the Unweighted Pair-Group Average (UPGMA) method, using the centralized and reduced data. For this analysis, the chemical and biological variables of the soil and the residue with the greatest chance of differentiating the groups were chosen, and the graphs were generated by the XLSTAT program version 2016.1 (Addinsoft Inc., Brooklyn, NY, USA).

RESULTS AND DISCUSSION

Chemical analysis

Considering the biomass and the nutrient contents of the recently applied organic residue (T1) in the plantation (Table 2) it was possible to estimate the potential supply of macronutrients and sodium to the system (g m^{-2}): K (121.4) > N (94.8) > Ca (23.1) > Mg (22.1) > Na (14.2) > P (9.9) > S (5.7); in addition to that of micronutrients (mg m^{-2}): Fe (966.5) > Mn (175.5) > Zn (86.0) > Cu (66.1). In the same way, the remainder of the residue which had been applied 72 months before (T4) had the following proportions (%): Mn (59.6) > Ca (58.1) > N (56.1) > Fe (50.7) > S (50.2) > Zn (47.8) > Mg (46.1) > P (38.6) > Cu (37.7) > Na (20.0) > K (5.6) in relation to the remaining residue in the T1 part of the plantation.

Over 72 months, there was a decrease of approximately 50% in the total of the biomass applied, showing high resilience in the mineralization of the residue process. It should be noted that this residue contains high levels of lignin (40%) and cellulose (25%), compounds that confer higher resistance to degradation (CABRAL *et al*., 2017).

Table 2 - Characteristics of the remaining crushed green coconut shell and the topsoil in the orchard with dwarf coconut palm trees

Attributes	Unit	T1	T2	T3	T4	T5	CV (%)
				Remaining residue			
Biomass	(kg m^{-2})	9.93 a	9.61 a	9.36 a	4.98 b		13.9
TOC	(g kg^{-1})	381.8 a	380.5 a	420.4 a	393.4 a		10.2
N	(g kg^{-1})	9.55 a	11.45 a	8.77 a	10.69 a		45.9
P	(g kg^{-1})	1.00 a	0.75 a	0.47 a	0.77 a		36.7
K	(g kg-^{1})	12.23 a	5.65 a	4.42 a	1.37 a		85.2
C:N ratio	-	40.0 a	33.2 a	47.9 a	36.8 a		55.2
C:P ratio	-	381.8 b	507.3 ab	894.5 a	510.9 ab		33.0
C:K ratio	-	31.2 a	67.3 a	95.1 a	287.2 a		87.5
Ca	(g kg^{-1})	2.33 a	1.25 a	1.72 a	2.70 a		78.2
Mg	(g kg^{-1})	2.23 a	1.82 a	1.87 a	2.05 a		36.9
S	(g kg^{-1})	0.57 a	0.45 a	0.52 a	0.57 a		30.7
Na	(g kg^{-1})	1.43 a	0.65 a	0.45 a	0.57 a		90.3
Cu	(mg kg^{-1})	6.66 a	3.75 a	3.50 a	5.00 a		34.3
Fe	(mg kg^{-1})	97.33 a	66.50 a	82.25 a	98.33 a		38.5
Mn	(mg kg^{-1})	17.67 a	16.25 a	15.00 a	21.00 a		58.8
Zn	(mg kg^{-1})	8.66 a	6.25 a	6.00 a	8.25 a		37.3

Continuation Table 2

Topsoil (0-0.1 m layer)							
TOC	(g kg^{-1})	5.18 a	5.33 a	6.28 a	3.76 b	3.36 b	16.9
N	(g kg^{-1})	0.15 ab	0.22 a	0.10 ab	0.04 b	0.16 ab	49.2
C:N ratio	-	34.5 b	24.2 b	62.8 ab	94.0 a	21.0 b	53.2
P	(mg dm^{-3})	6.33 cd	28.17 a	21.87 b	10.97 c	2.47 d	24.5
K^+	($mmol_c$ dm^{-3})	0.63 d	6.55 a	4.18 b	1.72 c	0.50 d	21.6
Ca^{2+}	($mmol_c$ dm^{-3})	19.33 ab	15.83 ab	21.67 a	10.67 b	14.33 ab	35.7
Mg^{2+}	($mmol_c$ dm^{-3})	9.33 ab	9.83 ab	13.33 a	8.17 ab	6.67 b	32.1
Na^+	($mmol_c$ dm^{-3})	0.67 ab	0.83 a	0.17 bc	0.17 bc	0.00 c	95.8
Cu	(mg dm^{-3})	0.13 b	0.12 b	0.12 b	0.12 b	0.38 a	66.3
Fe	(mg dm^{-3})	24.50 cb	29.33 b	22.67 c	20.50 c	35.50 a	11.7
Mn	(mg dm^{-3})	6.83 a	6.27 ab	7.63 a	3.13 b	9.40 a	29.2
Zn	(mg dm^{-3})	0.27 b	0.52 b	0.77 b	0.45 b	1.85 a	44.6
pH in H_2O	-	6.13 c	6.48 bc	6.83 b	6.37 c	7.47 a	3.5
$H+Al^{3+}$	($mmol_c$ dm^{-3})	26.65 a	34.27 a	12.53 bc	23.35ab	0.00 c	42.0
CEC	($mmol_c$ dm^{-3})	56.61ab	67.31 a	51.88 ab	44.08 b	21.50 c	14.4
SB	($mmol_c$ dm^{-3})	29.96 ab	33.04 ab	39.35 a	20.73 b	21.50 b	30.9
BS	(%)	52.9 bc	49.1 c	75.8 b	47.0 c	100.0 a	20.6

TOC: total organic carbon; CEC: cation exchange capacity; SB: sum of base; BS: base saturation. T1: one month of the residue and soil reaction; T2: 12 months of the residue and soil reaction; T3: 36 months of the residue and soil reaction; T4: 72 months of the residue and soil reaction; T5: no residue application (control). Average followed by the same letter in the line do not differ (p=0.05) by Tukey test

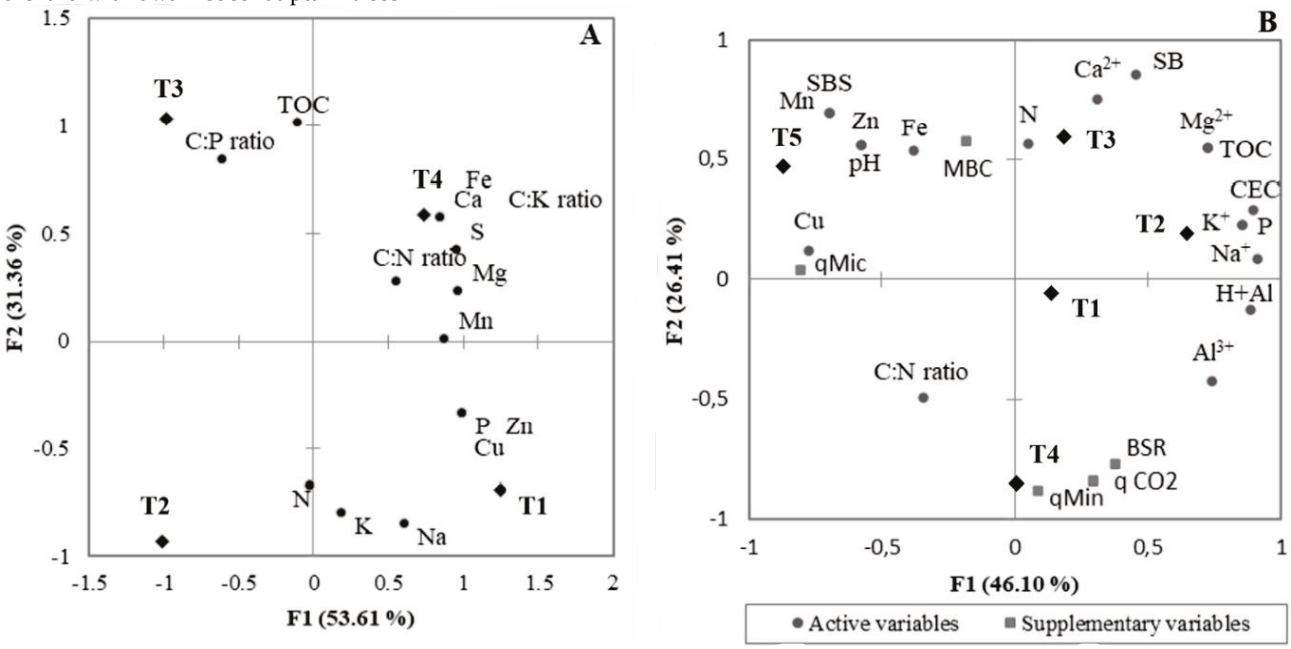
In T3, the high C:P (894.5) ratio may be associated with the active microbiota in the residue. Nevertheless, the ratio of C:P was considered high (> 380) in all the treatments. A high ratio of C:P indicates immobilization of P in the soil in the decomposition process of organic matter (MALUF *et al*., 2015).

In the PCA using the nutrient concentrations of the residue remaining in the orchard (Figure 1A), the first two components (F1 = 53.61%, F2 = 31.36%) explained most of the variations in terms of TOC and mineral contents in the coconut shell and the other components were therefore disregarded. The weights between the variables and these two main components reveal the variables that most affect the decomposition process of that organic material. The variables in F1 with the highest correlation were: P, Cu, Zn, Mg, S, Ca, Fe, Mn, and C:K ratio; contributing to about 10% (each) of the variability in this component. The TOC was strongly correlated with F2, which, on its own, contributed to 20% variability, followed by C:P ratio, Na and K contents. The correlations of TOC with other elements, such as Fe, Ca, S, Mg and Mn may be explained by the high affinity of these elements with carboxylic and phenolic groups in organic matter and this is why they are generally associated with the organic fraction of soils (SPARKS, 2003). The TOC was not related to elements such as Na and K, present in the bottom right quadrant.

In Figure 1A a clear separation of the treatments can be seen, confirming the chemical variation in the composition of the coconut residue over time. The residue that had been recently applied (T1) is in the bottom right quadrant, and the treatments move counterclockwise on the graph as the time the residue had been applied to the area increases. Although the T1 and T4 treatments were located on the right side of the graph due to the greater content of most minerals, the analysis of clusters (Figure 2A) separated them in different groups, probably due to the very low C: P ratio and very high K and Na contents in the newly applied residue (T1).

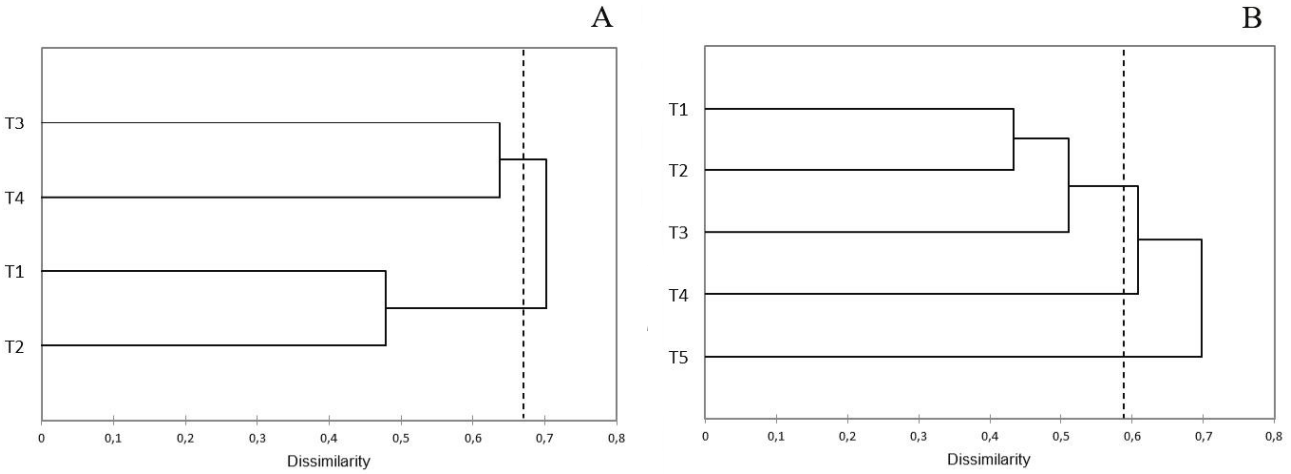
The topsoil fertilized with crushed green coconut shell showed variations in most of chemical and microbiological attributes throughout the time periods evaluated (Table 2). The increase in TOC contents in treatments T1 to T3 may be due to the release of compounds from the crushed green coconut shell applied to the soil surface, while the decrease in the TOC content in the T4 treatment, at a value close to the control (T5) can be explained by the mineralization of these compounds. The decrease in the TOC content, especially between 36 (T3) and 72 months (T4) suggests the need to reapply the crushed green coconut shell to maintain soil quality.

Figure 1 - Principal Component Analysis (PCA) results of the characteristics of the remaining crushed green coconut shell (A) and based on chemical plus supplementary biological attributes of the topsoil (B) evaluated in different treatments in the orchard with dwarf coconut palm trees



T1: one month of reaction of the residue with the soil; T2: 12 months of reaction of the residue with the soil; T3: 36 months of reaction of the residue with the soil; T4: 72 months of reaction of the residue with the soil; T5: no residue application (control). TOC: total organic carbon; CEC: cation exchange capacity; SB: sum of base; BS: base saturation; BSR: basal soil respiration; MBC: microbial biomass carbon; qCO_2: metabolic quotient; qMic: microbial quotient; qMin: mineralization quotient

Figure 2 - Dendrogram constructed by UPGMA of the characteristics of the remaining crushed green coconut shell (A) and based on chemical plus supplementary biological attributes of the topsoil (B) evaluated in different residue application in the dwarf coconut palm trees orchard



T1: one month of reaction of the residue with the soil; T2: 12 months of reaction of the residue with the soil; T3: 36 months of reaction of the residue with the soil; T4: 72 months of reaction of the residue with the soil; T5: no residue application (control)

There was an increase in acidity (pH in H_2O) in T3, a rise in contents of available P and exchangeable K^+ in the intermediate treatments (T2 and T3), and an increase of C:N ratio in the T4 soil, comparing them to the area where the residue had been recently applied (T1). There was also a reduction in potential acidity ($H+Al^{3+}$) in T3 when compared to T1.

The low K^+ content in T4 is due to the leaching to which it is susceptible in open systems, where it is affected directly by rain and irrigation, leading to a more rapid

release during the decomposition process of organic residue (SILVA; ROCHA; SILVA, 2018). This favors the leaching processes, since in the sandy soils there is a high drainage rate, which can be potentiated in Quartzipsamments because there is a low cohesion among the particles in these soils, due to a low proportion of cementing agents (SALES *et al*., 2010). In addition to K^+ mobility, there is a high demand for the element in the production of coconut bunches (SALDANHA e*t al*., 2017), which could justify covering the orchard soil with crushed coconut shell.

Due to the high concentration of K in the residue (Table 2), it was expected there would be a higher content of K in the soil of the treatment to which the residue had just been applied (T1) but the residue and soil samples were collected in the dry period of year, which slowed their reaction. In a similar way to what was observed in this study, Miranda, Sousa and Crisostomo (2007) evaluated the effects of the incorporation of green coconut shell residue and observed that there was an increase of K^+ after one year of incorporation.

The reduction of active acidity (pH) in the treatments fertilized with residue can be explained by the release of organic acids from the crushed green coconut shell. Other factors involving the higher absorption of cations (Ca^{2+}, Mg^{2+}) also imply a change of pH in the soil. However, even with a lower active acidity, treatment T4 and the other treatments (except T3) fell within the appropriate range of pH 6.0 to 6.5, since the coconut trees adapt well to slightly acidic to alkaline soils (MALHOTRA *et al*., 2017).

The availability of the micronutrients (Cu^{2+}, Fe^{2+} and Zn^{2+}) was, in turn, higher and the content of TOC, Na^+, CEC value and potential acidity were lower in the control area (T5). Higher contents of Na^+ were detected in the soil after 12 months of application (T2) than in the area where the residue had been recently applied (T1), and higher contents of Ca^{2+} and Mg^{2+} were found in T3 than in T4 and T5, respectively (Table 2).

The contents of assimilable P in the soil fell from the amount seen in treatment T2 (28.17 g dm^{-3}), to T3 (21.87 g dm^{-3}), to T4 (10.97 g dm^{-3}) and T5 (2.47g dm^{-3}) (Table 2), which shows the effect that residue application periods have on the amount of P available in the soil. The decrease in P content which occurs with the increase in the reaction time of the residue with the soil can be explained by the rapid release of that element at the beginning of the decomposition period due to immobilization of the water-soluble P fraction by the active soil biomass. Similar results were found by Miranda, Sousa and Crisóstomo (2007), who detected 22.33 and 2.34 mg kg^{-1} of P in the first and second year after the application of the same residue, respectively.

The CEC value shows another positive effect of coconut shell residue on the soil, as the treatments which received that material had a significant increase (Table 2) in relation to the treatment without the addition of organic material (T5). The increase in CEC is favorable, especially for the soil in question, as it presents a predominance of the sand fraction (Table 1) and the clay fraction, as it was developed from sediments from the Barreiras Formation, which is kaolinitic, with a low degree of structural order (GIAROLA *et al*., 2009), causing low CEC values.

The PCA using the nutrient contents of the topsoil (Figure 1B) corroborated the Anova results. The areas where the residue was applied for shorter periods were more closely related to each other (T1, T2, and T3), showing direct correlation with high amounts of variables located at positive loadings of PC1, while the higher C: N ratio was highlighted in the treatment with longer decomposition of the residue (T4). The increase of the C: N ratio in T4 (94.0), indicates the immobilization of N (SHENG *et al*., 2018), while the lower values observed in the recently applied residue treatment T1 (34.5) suggest a greater capacity for mineralization, favoring the process of absorption and exportation of N by the coconut palm trees. It should be noted that the addition of residues to the soil accelerates the dynamic of soil organic matter decomposition (JACKSON *et al*., 2019). This process does not, however, mean that there will be an increase of C in the soil, as can be seen in T4. It may be that other factors, including a reduction in active acidity (pH = 6.37) limit the availability of the complex assortment of nutrients in the soil.

It should be noted that the areas with 72-month-old coconut palm trees, without application (T5) or with application of crushed green coconut shell (T4), had different properties in terms of soil fertility. The soil of the control area was characterized by higher levels of pH, Cu, Zn, Fe, Mn and SB. The gaps between T5 and T4 and the other treatments were confirmed by AHC (Figure 2B), indicating that the area where no residue was applied and the area where it was applied and left for 72 months had their chemical attributes significantly altered, meaning they were markedly different from the other areas, where the soil was covered with residue for shorter periods of time.

Microbiological analysis

In general, microbiological attributes were affected positively by the application of residue on the soil surface (Table 3), which was to have been expected. Higher microbial biomass carbon (MBC) levels were detected in the intermediate period treatments (T2 and T3). In addition, higher base soil respiration (BSR) levels, metabolic (qCO_2) and mineralization (qMin) quotients were found

in T4 than in the soil with recently applied residue (T1). On the other hand, the microbial quotient (qMic) was higher in the control area (T5) than it was in the areas where residue had been applied. This can be seen clearly in Figure 1B, where five microbiological attributes were used as supplementary variables in the PCA of topsoil, and whose vectors were plotted according to correlations with the chemical attributes. In addition, the increase in qMic and MBC occured alongside an increase in other components, such as active acidity (pH), Mn, Zn, Cu and Fe, while the increase of qMin, qCO_2 and BSR was inversely correlated with those chemical variables, mainly BSR with Fe (r = -1,00). The distancing of the microbiological variables to the upper right quadrant indicates a low relationship with the increase in chemical components with positive loadings for PC1 and PC2, as well as low levels in the areas T1, T2 and T3, which were covered with the residue residue for shorter periods.

The higher values of qMic in the soil of the control treatment confirms a certain equilibrium in microbial activity in immobilizing organic C, corroborating the observations made by Dadalto *et al*. (2015). The low level of MBC detected in T4 may reflect the perturbation of soil microbiota, something that can be attributed to the greater energy expenditure in keeping the microbiota active, and to the energy used during the topsoil organic matter decomposition process. It should be noted that the dynamics of SOM decomposition reflects in the soil structure (JACKSON *et al*., 2019). According to Boeni *et al*. (2014), plant residues are able to supply higher concentrations of organic C to the soil in the first three years. However, Oliveira *et al*. (2018) highlight that in soils that do not have fertility restrictions, organic residues can promote the accumulation of TOC for longer periods of time. Furthermore, an unfavorable condition for the soil microbiome was observed when the highest values

Table 3 - Microbiological attributes and arbuscular mycorrhizal fungi (AM) with respective relative abundances and frequency (Freq) in the topsoil subjected to treatments with crushed green coconut shell in the dwarf coconut palm trees orchard

Microbiological attributes	T1	T2	T3	T4	T5	CV (%)
BSR (µg C-CO_2 g^{-1} soil day^{-1})	4.50 bc	4.12 bc	5.17 b	9.23 a	1.88 c	35.3
MBC (µg Cmic g^{-1} soil)	334.1 b	561.7 a	511.5 a	394.9 b	557.9 a	13.5
qCO_2 (µg C-CO_2 $µg^{-1}$ Cmic day^{-1})	1.36 b	0.74 bc	1.01 bc	2.42 a	0.32 c	40.3
qMic (%)	6.58 b	10.57 b	8.24 b	11.29 b	17.57 a	29.8
qMin (%)	3.64 b	3.14 b	3.51 b	10.53 a	2.52 b	50.0
	AM fungi communities					
Spores (nº 50 g^{-1} soil)	187.3 a	189.7 a	172.0 a	110.0 a	169.7 a	44.8
Genera (nº 50 g^{-1} soil)	3.3 a	4.3 a	4.7 a	3.0 b	4.3 a	14.3
Species (nº 50 g^{-1} soil)	4.7 a	5.3 a	6.3 a	3.6 a	5.0 a	24.3
AM fungi species	Relative abundances (%)					Freq (%)
Acaulospora laevis	80.8	71.2	58.1	25.5	83.3	93.3
Acaulospora scrobiculata	0.7	1.4	5.4	19.6	0.0	60.0
Acaulospora mellea	0.0	0.0	3.9	0.0	0.0	13.3
Claroideoglomus etunicatum	10.6	12.0	10.9	25.5	0.0	73.3
Dentiscutata colliculosa	0.7	0.0	3.1	0.0	0.0	20.0
Dentiscutata hawaiensis	0.0	3.5	3.1	0.0	3.2	46.7
Dentiscutata biornata	1.5	0.0	0.0	0.0	1.6	20.0
Gigaspora ramisporophora	0.0	0.0	0.0	0.0	0.8	6.7
Funneliformis geosporum	0.0	7.7	0.0	29.3	7.2	46.7
Glomus brohultii	2.8	0.0	7.7	0.0	0.0	26.7
Cetraspora pellucida	0.0	1.4	7.0	0.0	3.2	46.7
Racocetra fulgida	1.4	0.7	0.8	0.0	0.8	33.3
Racocetra castanea	1.4	2.1	0.0	0.0	0.0	26.7

T1: one month of reaction of the residue with the soil; T2: 12 months of reaction of the residue with the soil; T3: 36 months of reaction of the residue with the soil; T4: 72 months of reaction of the residue with the soil; T5: no residue application (control). BSR: basal soil respiration; MBC: microbial biomass carbon; qCO_2: metabolic quotient; qMic: microbial quotient; qMin: mineralization quotient; Average followed by the same letter in the line do not differ (p=0.05) by Tukey test

of qCO_2 were used in T4, compared to other treatments with crushed green coconut shell. In that situation, the microbial biomass requires larger supplies of C to maintain its metabolic and soil ecosystem functions (VEZZANI *et al*., 2018), leading to the release of $C\text{-}CO_2$ into the atmosphere. In turn, the higher values of BSR and qMin in T4 may indicate intense microbial activity in decomposing organic residue, which may reflect an advantageous field condition for nutrient absorption by plants. Of all the attributes related to C, MBC accounted for almost all the differences between plantations with and without residue application, thus evidencing the use of this indicator in the identification of long-term changes in the establishment of a crop. However, the differences between areas in terms of the microbiological and chemical attributes related to the N element showed a lower correlation.

Regarding the spores of arbuscular mycorrhizal fungi (AM), 14 species from 8 genera were identified in the four areas treated with green coconut shell residue and the control area. There was found to be very low density of AM fungi genera in T1 (Table 3), which shows the negative impact the residue left for 72 months had on communities of *Dentiscutata* and *Racocetra* in the soil. There was, however, no change in the number of species and the density of the spores of these soil fungi. The diversity of species was maintained throughout the periods evaluated, but in terms of relative abundance the species *Acaulospora laevis*, *A. scrobiculata* and *Claroideoglomus etunicatum* stand out, with spore frequencies of 93.3%, 60.0% and 73.3%, respectively.

The species belonging to *Acaulospora* were more abundant in the soil, something which can be explained by the fact that species from the group are considered generalist, as they are present in many different soil and cultivation conditions, as set out by Oehl *et al*. (2010). It is worth mentioning the presence of *A. scrobiculata* and *C. etunicatum* spores in areas fertilized with coconut shell residue, both of which were absent in the soil of the control area. In the control area soil, however, rarer and more strategic fungi were found, such as *Gigaspora ramisporophora* and *Dentiscutata biornata*, species which were not detected in the areas fertilized with coconut shell for a year or more. These fungi may have longer life cycles, forming great networks of extraradical hyphae.

The genera *Claroideoglomus*, *Glomus*, *Gigaspora*, *Acaulospora*, *Funneliformis*, *Dentiscutata*, *Diversispora*, *Redeckera*, *Scutellospora* and *Septoglomus* have been shown to be common in the rhizosphere of coconut palm trees in India (RAJESHKUMAR *et al*., 2015), when they were intercropped. Spore communities of AM fungi can be modulated by soil attributes. There was less diversity of fungi genera in T4, where low values of base saturation (47.0%) were found and low active acidity (pH = 6.37) (Table 2), in addition to high values of basal soil respiration and metabolic quotient. According to Qiu *et al.* (2019), changes in pH, salinity, and other chemical properties interfere with mycorrhizal activity at the rhizosphere level of plants.

CONCLUSIONS

1. The application of 100 t ha^{-1} of crushed green coconut shell between the rows of the dwarf coconut palm plantations promotes changes in the chemical and microbiological soil attributes, especially in the first months of the application of the residue. Based on the TOC content of the soil, the reapplication of residue is recommended 36 months after the first application;
2. Organic fertilization with coconut shell residue affects the AM fungi, without affecting the diversity of their species in the soil. Morphotypes of prevalent fungi belong to the species *Acaulospora laevis, A. scrobiculata* and *Claroideoglomus etunicatum*.

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