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Biological Properties and Organic Matter Dynamics of Soil in Pasture and Natural Regeneration Areas in the Atlantic Forest Biome

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ABSTRACT: The removal of original vegetation for crops and pasture production and then followed by natural regeneration is a standard practice in the Atlantic Forest, which has produced patches with different degrees of degradation and regeneration across the landscape. The aim of this study was to evaluate the effects of replacement of native forest by pasture and natural regeneration of vegetation on soil and on soil organic matter (SOM) dynamics in the dry and rainy season in an Atlantic Forest fragment in Passa Vinte, Minas Gerais (MG), Brazil. Soil samples were collected in the rainy and dry season, at a depth of 0.00-0.05 m. The variables determined were total organic carbon (TOC) and particle-size fractions of SOM [particulate organic carbon (POC) and mineral-associated organic carbon (MOC)]; microbial activity by basal respiration (BR) and microbial biomass carbon (MBC); species richness (SR) and spore abundance (SA) of arbuscular mycorrhizal fungi (AMF); and total and easily extractable glomalin-related soil protein (T-GRSP and EE-GRSP, respectively). The conversion of native forest into pasture reduced TOC, POC, MOC, AMF-SA, T-GRSP, and EE-GRSP. However, it did not reduce MBC and BR. The fallow period in the area under natural regeneration was not long enough to restore soil TOC, POC, MOC, BR, MBC, T-GRSP, and EE-GRSP to levels approaching those observed in the forest area. Nevertheless, natural regeneration of vegetation stimulated the production of seedlings (spores) of arbuscular mycorrhizal fungi, which are important for the establishment of plant species and advance of ecological succession. Seasonality affected some of the biological soil properties and SOM dynamics.

Keywords: organic carbon, microbial biomass, arbuscular mycorrhizal fungi, biodiversity, forest fragment.

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INTRODUCTION

Under balanced conditions, the Atlantic Forest provides continuous benefits to the environment, contributing to climate regulation, nutrient cycling, maintenance of biodiversity, and genetic variability (Lima et al., 2014). Despite the important social, economic, and environmental functions of this biome, it has been reduced to only 8 % of its original area, making it crucial to adopt efficient conservation and recovery measures (Carvalhal et al., 2015).

A common practice in Atlantic Forest areas has been substitution of natural forests for crops and pastures, followed by natural recovery of vegetation, which produces a landscape containing patches with different degrees of degradation and recovery. These practices can affect ecosystem equilibrium and the chemical, physical, and biological properties of soil, which can be considered indicators of environmental degradation and recovery (Machado et al., 2010; Silva et al., 2012a; Guareschi et al., 2014).

With transformation of forest to other types of land use, factors such as plant input, quality of residues, and decomposition rates lead to drastic changes in soil organic matter (SOM) and soil fractions (Loss et al., 2014). Organic matter determines the physical, chemical, and biological properties of soil and is considered one of the main indicators of its quality (Doran and Parkin, 1994; Reichert et al., 2003; Leite and Galvão, 2008; Braida et al., 2011). These changes also affect microbial biomass, one of the components that, along with macrofauna and plant roots, represent the live portion of SOM (Brookes, 2001; Moreira and Malavolta, 2004). Microbial biomass controls important soil functions, such as organic matter decomposition and accumulation, in addition to transformations involving nutrients (De-Polli and Guerra, 1999).

Changes in land use affect the community of arbuscular mycorrhizal fungi (AMF) (Silva et al., 2006; Ferreira et al., 2012), microorganisms that play an important role in plant development, especially in the first stages of ecological succession, because, in conjunction with plant roots, they improve water and nutrient uptake (Siqueira et al., 1998; Zangaro et al., 2000). In addition, they affect the physical properties of soil by mechanisms such as production of glomalin, a protein that serves as a binding agent for soil particles, promoting aggregate formation and stability (Wright et al., 1996; Morell et al., 2009). Given its role in aggregation, glomalin contributes significantly to ecosystem sustainability (Sousa et al., 2012), enhancing water infiltration, gas exchange, and root growth, decreasing erosion and increasing C storage capability (Rillig et al., 1999; Sousa et al., 2012).

Evaluation of glomalin as a gene product in soil is inaccurate, due to limitations of the Bradford and Elisa method, which is usually used for its extraction and quantification (Whiffen et al., 2007; Sousa et al., 2012). Thus, glomalin has been operationally assessed as a glomalin-related soil protein (GRSP) (Rillig, 2004), considered an indicator of soil quality with good sensitivity for detecting impacts from different soil use and management systems (Silva et al., 2012b; Silva et al., *in press*).

The hypothesis of the present study is that the conversion of Atlantic Forest into pasture and then to areas of natural regeneration changes the biological properties and dynamics of SOM, and it is also affected by seasonality. The objective was therefore to assess the effects of replacing native forest by pasture and areas of natural regeneration on biomass activity and microbial biomass carbon (MBCn), AMF spore abundance (SA), AMF species richness (SR), GRSP, total organic carbon (TOC), and the particle size fractions of SOM in the dry and rainy season in an Atlantic Forest fragment in Passa Vinte, MG, Brazil.

MATERIALS AND METHODS

The study was performed on the Palmital farm in Passa Vinte, MG (22° 12’ S, 44° 12’ W; 630 m altitude). Climate is characterized as humid subtropical (Cwa) according to the

Köppen classification system, with average annual temperature of 19.3 °C and rainfall of 1,494 mm. July is the driest month, with average rainfall of 16 mm, whereas the highest average rainfall of 269 mm occurs in January. Soil in the area is classified as *Argissolo Vermelho-Amarelo* (Ultisol) (Santos et al., 2013) and topography ranges from slightly rolling to rolling. Sampling was performed in secondary forest, natural pasture, and natural regeneration areas, and sampling points were located approximately 10 m apart.

The forest area was located in the upper third of a toposequence and corresponded to a fragment of Atlantic Forest biome, with an ecosystem characteristic of a Submontane Ombrophilous Dense Forest. Since the landowners acquired the property, cutting in the area has not been registered, but it appears to have occurred in secondary forest, based on the historical features, size, and distribution of forest fragments. The ecological features and the presence of ample biodiversity of large animals observed by the landowners indicate a prolonged period of formation. The natural pasture area was located at the top of the toposequence, facing west-southwest, with a slope of less than 45°. It is predominantly covered by low densities of brachiaria grass trampled by animals. The regeneration area, located in the lower third of the toposequence, was used as pasture until it was fenced to avoid cattle incursions. It was last cleared nearly 20 years ago.

Soil samples were collected during the dry season (September 2013) and at the end of the rainy period (April 2014). Chemical and physical properties of the soil samples were characterized according to Donagema et al. (2011) (Table 1).

A 1-ha plot was demarcated in each area, and five soil samples were collected in both seasons at a depth of 0.00-0.05 m, producing five compound samples per area and season. A portion of each sample was air dried, broken up, and sieved through 1-mm mesh to obtain air-dried fine earth (ADFE), which was used to determine C and particle-size fractions. The remaining fraction of the sample was processed immediately after collection for microbiological characterization.

Total organic carbon (TOC) was evaluated according to Yeomans and Bremmer (1988), and SOM particle size fractions were determined according to Cambardella and Elliott (1992), obtaining particulate organic carbon (POC) and mineral-associated organic carbon (MOC). Quantification of microbial activity was based on soil basal respiration (BR) and metabolic quotient (qCO_2), carried out in accordance with Jenkinson and Powlson (1976). Microbial biomass carbon (MBC) was determined by fumigation/extraction, as proposed by Vance et al. (1987). The microbial quotient (*q*MIC) was calculated from the ratio between soil MBC and TOC.

Arbuscular mycorrhizal fungi (AMF) of each sample were evaluated in 50 cm^3 soil samples for spore extraction using the wet sieving method (Gerdermann and Nicolson, 1963). After spore counting to determine spore abundance (SA), species were identified according to Schenck and Perez (1988) and the descriptions provided by the INVAM (International Culture Collection of Arbuscular and Vesicular-Arbuscular Mycorrhizal Fungi, Morgantown,

Table 1. Chemical and physical properties of topsoil (0.00-0.05 m) in areas of natural regeneration, natural pasture, and a fragment of native forest on the Palmital farm in Passa Vinte, MG, Brazil, sampled in the dry and rainy season

Area	pH(H_2O)		Ca^{2+}		Mg^{2+}		K^+		P		Sand	Silt	Clay
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry		
			cmol$_c$ kg^{-1}						mg kg^{-1}		g kg^{-1}		
Forest	4.21 b	4.35 a	0.74 b	0.91 a	1.37 a	1.10 a	0.37 a	0.08 a	3.52 a	3.19 a	441 b	176 a	383 a
Pasture	5.07 a	4.28 a	1.84 a	0.75 a	2.12 a	0.09 b	0.36 a	0.04 a	2.53 b	1.98 b	460 ab	208 a	332 b
Regeneration	4.41 b	4.48 a	0.33 c	0.57 a	0.37 b	0.13 b	0.16 b	0.04 a	1.74 c	1.05 c	532 a	153 a	315 b
CV (%)	3.26		15.60		20.72		22.41		19.52		8.04	19.05	8.04

Means followed by the same uppercase letter in a row and the same lowercase letter in a column do not differ statistically (Bonferroni t test, p=0.05).

WV, USA - http://invam.caf.wvu.edu/). Based on AMF identification, we calculated species frequency (Fi) (Brower et al., 1990) (Fi = ji/Ke, where ji is the number of samples containing species i, Ke the number of soil samples, Fi the species frequency i); total species richness (SR); and the Margalef index (Dα = [(n-1)]/ln N, where Dα is diversity, n is the number of species recorded, N is the number of individuals of any species in the sample, and ln is the natural logarithm of N).

Soil glomalin was quantified as glomalin-related soil protein (GRSP). The two GRSP fractions, total (T-GRSP) and easily extractable (EE-GRSP), were distinguished as a function of extraction conditions (Wright and Upadhyaya, 1998). Both fractions were extracted in auclave - EE-GRSP with 1 g of soil in 8.0 mL of 20 mmoL L^{-1} sodium citrate solution (pH 7.4) at 121 °C for 30 min, and T-GRSP with 1 g of soil in 8.0 mL of 50 mmoL L^{-1} sodium citrate solution (pH 8.0) at 121 °C for 60 min. More than one autoclave cycle was needed to extract T-GRSP, and these cycles were repeated until the sample turned light yellow. After autoclave protocols, both GRSP fractions were centrifuged at 5,000 g for 20 min to quantify protein in the supernatant. GRSP was quantified using the Bradford method (Bradford, 1976), modified by Wright et al. (1996) (available at http://www.usda.gov), using bovine serum albumin (BSA) as a standard. The GRSP concentrations for both fractions were corrected to mg g^{-1} of soil considering the total volume of supernatant and soil dry matter.

Homoscedasticity and data normality were tested before performing analysis of variance and test of means. The results obtained were analyzed for normality of error distribution using the Lilliefors test and homogeneity of variance by the Cochran and Bartlett test, performed with SAEG 5.0 software. Means were compared by the Bonferroni t test, conducted using Sisvar 4.6 software. Cluster analysis and principal component analysis (PCA) were performed using PAST software (Hammer et al., 2004).

RESULTS AND DISCUSSION

Total organic carbon and particle size fractions of organic matter

Total organic carbon (TOC) levels in the dry and rainy season were higher in the forest, intermediate in pasture, and lower in the regeneration area (Table 2). Forest conversion into pasture and areas of natural recovery reduced soil TOC by nearly 40 %. Pasture and regeneration areas likely receive lower plant residue (leaves and branches) input on the soil surface, explaining the decline in TOC (Bernini et al., 2009). A decrease in TOC is a negative impact of pasture establishment because, according to Bernini et al. (2009), it can reduce nutrient cycling. The findings indicate that the fallow period in the recovery area was not long enough to return TOC levels to those observed in the forest area.

Table 2. Total organic carbon (TOC), particulate organic carbon (POC) and mineral associated organic carbon (MOC) in topsoil (0.00-0.05 m) sampled in the dry and rainy season in forest, pasture, and natural regeneration areas on the Palmital farm in Passa Vinte, MG, Brazil

Area	TOC		POC		MOC	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
	g kg^{-1}					
Forest	45.42 aA	42.36 aB	10.24 aA	9.90 aA	35.52 aA	32.12 aB
Pasture	26.02 bA	23.70 bB	7.83 bA	7.45 bA	18.57 bA	15.87 bB
Regeneration	23.88 cA	20.82 cB	7.76 bA	5.38 cB	18.50 bA	13.06 bB
CV (%)	2.10		14.22		7.94	

Means followed by the same uppercase letter in a row and the same lowercase letter in a column do not differ statistically (Bonferroni t test, p=0.05).

In both the rainy and dry seasons, the forest area also exhibited the highest POC levels. Only in the rainy season did POC levels differ between pasture and regeneration areas, with lower values in the latter. In the state of Acre, Bernini et al. (2009) observed that replacing original vegetation by pasture decreased TOC and POC, showing that these fractions are indicators of changes in land use in that ecosystem. Composed of fungal hyphae, plant roots, and animal and plant residues, POC corresponds to the labile fraction of SOM and is very sensitive to changes in land use and management (Blair et al., 1998).

Mineral-associated organic carbon (MOC) showed the same pattern as TOC and POC, with the highest levels detected in the forest area (Table 2), in both seasons. However, no difference was detected between pasture and regeneration areas (Table 2). Mineral-associated organic carbon, however, might not be a good indicator of the effects of land use systems on soil properties because it may take several years for changes in this SOM fraction to become detectable (Carmo et al., 2012). This occurs because of slow MOC cycling, interaction with the mineral fraction of the soil, and the formation of stable organomineral compounds (Bayer et al., 2004; Carmo et al., 2012).

Total organic carbon (TOC) declined by 10 % and POC by 18 % in the rainy season in comparison to the dry season. This is likely due to the increase in SOM mineralization that occurs in the rainy season as result of microbiota activity stimulated by high temperatures and rainfall (Gama-Rodrigues et al., 2005).

Carbon and microbial biomass activity

Microbial biomass carbon (MBC) did not differ between pasture and forest areas in either season, but in the dry season it was lower in the regeneration area than in the forest area (Table 3). Similar MBCs between native forest and pasture areas were also found in studies carried out in São Paulo (Marchiori Júnior and Mello, 1999) and Rio de Janeiro (Silva et al., 2012a).

The higher MBC in forest may be associated with the greater organic matter input and with high floristic diversity, which likely promotes the development of microbial biomass (Menezes, 2008; Silva et al., 2010, 2012a). In pasture areas, high MBC is associated with the root system of grasses, which is abundant and active throughout the year (Marchiori Júnior and Mello, 1999), and also with animal-derived organic matter (Toda et al., 2010), which likely enhanced the availability of organic substrates for soil microbiota (Oliveira et al., 2001). Toda et al. (2010) found that pasture areas exhibit higher content of animal-derived organic matter and MBC compared to different cropping systems. In addition, Vicente and Araújo (2013) observed that, over the years, microbial biomass tends to increase in land covered with pasture, due to the significant development of a grass root system and its cycling potential in topsoil. In the natural recovery area, the inputs of oxidizable C might not meet the demands for maintaining existing biomass (D'Andréa et al., 2002).

Table 3. Microbial biomass carbon (MBC), and activity (soil basal respiration - BR, metabolic quotient - *q*CO_2, and microbial quotient - *q*MIC) in topsoil (0.00-0.05 m) sampled in the dry and rainy season in forest, pasture, and natural regeneration areas on the Palmital farm in Passa Vinte, MG, Brazil

Area	MBC		BR		*q*CO_2		*q*MIC	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
	mg kg^{-1}		mg CO_2-C kg^{-1} h^{-1}		mg CO_2-C mg^{-1} CBM h^{-1}		%	
Forest	365 aB	543 abA	4.49 aA	3.42 aB	14.32 abA	6.84 aB	0.80 aB	1.28 bA
Pasture	296 abB	635 aA	4.48 aA	3.54 aA	17.14 aA	5.74 aB	1.14 aB	2.68 aA
Regeneration	207 bB	474 bA	2.15 bA	1.98 bA	11.88 bA	4.35 aB	0.87 aB	2.28 aA
CV (%)	20.77		21.39		17.46		14.46	

Means followed by the same uppercase letter in a row and the same lowercase letter in a column do not differ statistically (Bonferroni t test, p=0.05).

Microbial biomass carbon levels were higher in the rainy season than in the dry season, likely because increased temperature and rainfall produced conditions favorable to microbial biomass development (Espíndola et al., 2001). Basal respiration (BR) was also higher in forest and pasture areas, in both seasons, indicating higher rates of CO_2 emission compared to the regeneration areas (Table 3). In the native forest area, this pattern may be related to constant litter deposition and residue incorporation, prompting organic matter build up and producing high biomass and biological activity in this material (Silva et al., 2012a; Islabão et al., 2015). Litter incorporation can lead to a five-fold increase in the biological activity of soils (Della Bruna et al., 1991), a desirable feature, given that microbial activity may represent rapid transformation of organic residues into plant nutrients (Azar et al., 2013). Nutrient cycling in pasture areas may be faster because of high plant biomass renewal and intense biological activity, which increases BR (Silva et al., 2012a).

The metabolic quotient ($q\mathrm{CO_2}$) did not differ among the study areas, indicating similar response to mineralization (Martins et al., 2010). However, $q\mathrm{CO_2}$ was higher in the dry season in all areas. This response suggests higher energy use by the microbiota, likely because of stress or disturbance in the dry season (Tótola and Chaer, 2002).

The microbial quotient (*q*MIC) was similar among the areas in the dry season, but lower in the forest in the rainy season. Sparling (1992) underscores that *q*MIC is related to the efficiency of organic C conversion into microbial C and organic C loss and organic C stability in the mineral fraction of soil. Therefore, from the dry to the rainy season, a *q*MIC increase represents higher organic C content available to soil microbiota in the rainy season, that is, C that was stable in the organic form became unstable in the microbial form (Anderson and Domsch, 1989).

Arbuscular mycorrhizal fungi

The 10 AMF species observed in soil sampled in the dry and rainy season consisted of five families and six genera (Table 4). Three species belonged to the genera *Glomus* and *Acaulospora*, while the genera *Claroideoglomus*, *Gigaspora*, *Scutellospora*, and *Ambispora* were represented by a single species each. The species *Ambispora leptoticha*, *Acaulospora laevis*, *Claroideoglomus lamellosum*, and *Glomus macrocarpum* were observed in all the areas, in both the dry and rainy season, the last species being the most frequent (100 %) (Table 4). The species *Acaulospora foveata* and *Glomus clavisporum* were exclusive to the regeneration area, whereas *Acaulospora scrobiculata* was observed only in the pasture area (Table 4). One noteworthy aspect is that species not identified in a determinate area are not necessarily absent in that environment since they can be present in other forms (e.g. hyphae, colonized roots, and auxiliary cells), which are not detectable by the methods adopted in the present study (Santos et al., 2014).

In both seasons, the values of total SR and the Margalef diversity index were very similar among the areas (Table 5), indicating similar composition of AMF communities, ranging from 50 to 66 %. In the dry season, the AMF community had greater similarity between pasture and forest areas, while in the rainy season, the AMF community of the regeneration area had greater similarity to that of the forest fragment (Figure 1). This pattern suggests that the AMF community is affected not only by the host, but also by climatic conditions, and possibly by soil conditions (Silva et al., 2007).

Spore abundance (SA) did not differ between the forest and regeneration areas in either season evaluated, but lower values were observed in the pasture area (Table 5). In contrast, both EE-GRSP and T-GRSP levels were generally lower in regeneration and pasture areas compared to the forest area (Table 5), following the same pattern observed for TOC and particle size fractions of organic matter (Table 2). Many studies have emphasized the relationship between GRSP and organic C (Fokom et al., 2012; Silva et al., 2012b) and the importance of this protein for soil C pools (Nobre et al., 2015). The higher EE-GRSP

Table 4. Relative frequency of arbuscular mycorrhizal fungus species in topsoil (0.00-0.05 m) sampled in the dry and rainy season in forest, pasture, and natural regeneration areas on the Palmital farm in Passa Vinte, MG, Brazil

Family/Specie	**Relative frequency**					
	Forest		**Pasture**		**Regeneration**	
	Dry	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**
	%					
Archaeosporaceae						
Ambispora Leptoticha (Schenck and Smith) Walker, Vestberg and Schüssler	20	40	40	20	20	40
Acaulosporaceae						
Acaulospora laevis Gerderman and Trappe	40	60	100	80	100	100
Acaulospora foveata Trappe and Janos	-	-	-	-	20	20
Acaulospora scrobiculata Trappe	-	-	60	20	-	-
Gigasporaceae						
Gigaspora sp.	40	60	20	-	-	40
Scutellospora scutata Walker and Dieder	40	20	-	20	-	-
Claroideoglomeraceae						
Claroideoglomus lamellosum (Dalpé, Koske and Tews) Walker and Schüßler	60	80	20	20	60	60
Glomeraceae						
Glomus clavisporum (Trappe) Almeida and Schenck	-	-	-	-	20	40
Glomus macrocarpum Tulasne and Tulasne	100	100	100	100	100	100
Glomus tortuosum Schenck and Smith	40	60	-	-	40	60

Table 5. Total species richness (SR) and spore abundance (SA) of arbuscular mycorrhizal fungi (in 50 cm^{-3} soil), Margalef index (Dα), easily extractable (EE-GRSP) and total (T-GRSP) glomalin-related soil protein in topsoil (0.00-0.05 m) sampled in the rainy and dry season in forest, pasture, and natural regeneration areas on the Palmital farm in Passa Vinte, MG, Brazil

Area	**SR**		**SA**		**Dα**		**EE-GRSP**		**T-GRSP**	
	Dry	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**
							mg g^{-1}			
Forest	7	7	222 abA	311 aA	1.11	1.04	3.99 aA	2.73 aB	9.53 aB	23.86 aA
Pasture	5	6	182 bA	139 bA	0.77	0.81	2.85 bA	1.49 bB	5.96 abB	16.72 bA
Regeneration	7	8	364 aA	411 aA	1.02	1.00	1.93 bA	1.27 bA	4.68 bB	12.29 cA
CV (%)			25.57				26.12		20.33	

Means followed by the same uppercase letter in a row and the same lowercase letter in a column do not differ statistically (Bonferroni t test, p=0.05).

and T-GRSP levels in the forest area may be associated with the accumulation of this protein over time. This T-GRSP pattern was also observed by Silva et al. (2013) in native Atlantic Forest areas.

Multivariate analysis

Principal component analysis (CPA) of soil properties (TOC, POC, MOC, MBC, BR, $q\text{CO}_2$, qMIC, SA, T-GRSP, EE-GRSP) showed that 78.85 and 80.59 % of dry and rainy season data variability, respectively, were explained in the first two components (Figures 2a and 2b). The forest area was separated from regeneration and pasture areas in axis 1 in both the dry season (principal axis, A1 = 57.11 %) and rainy season (A1= 53.48 %) (Figures 2a and 2b). Most variables evaluated contributed to separating the areas (EE-GRSP, T-GRSP, MBC, BR, TOC, MOC, and POC in the dry season; EE-GRSP, T-GRSP, $q\text{CO}_2$, TOC, MOC, and qMIC in the rainy season) and showed correlation coefficients with axis 1 above 0.70. The variables were more associated with the forest area, likely because of the higher values exhibited in this area. This result shows the changes in these soil properties during native forest conversion into natural pasture and in a natural regeneration area. These findings corroborate a study on the fertility and organic matter content of forest and pasture soils in Acre (Loss et al., 2014).

The higher association between the forest area and the different C fractions and biological variables is explained by their particular situation. The variables under study are favored by the continuous input of organic materials, particularly plants at different degrees of

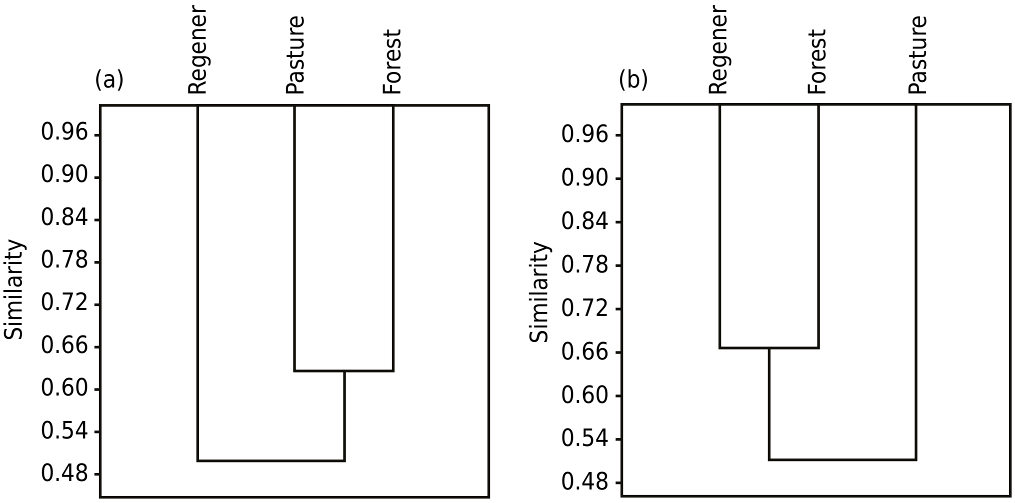

Figure 1. Dendrogram showing the frequency of arbuscular mycorrhizal fungi species in topsoil (0.00-0.05 m) from areas of natural regeneration (Regener.), natural pasture, and a fragment of native forest on the Palmital farm in Passa Vinte, MG, Brazil, sampled in the dry (a) and rainy (b) season (Jaccard similarity index was used)

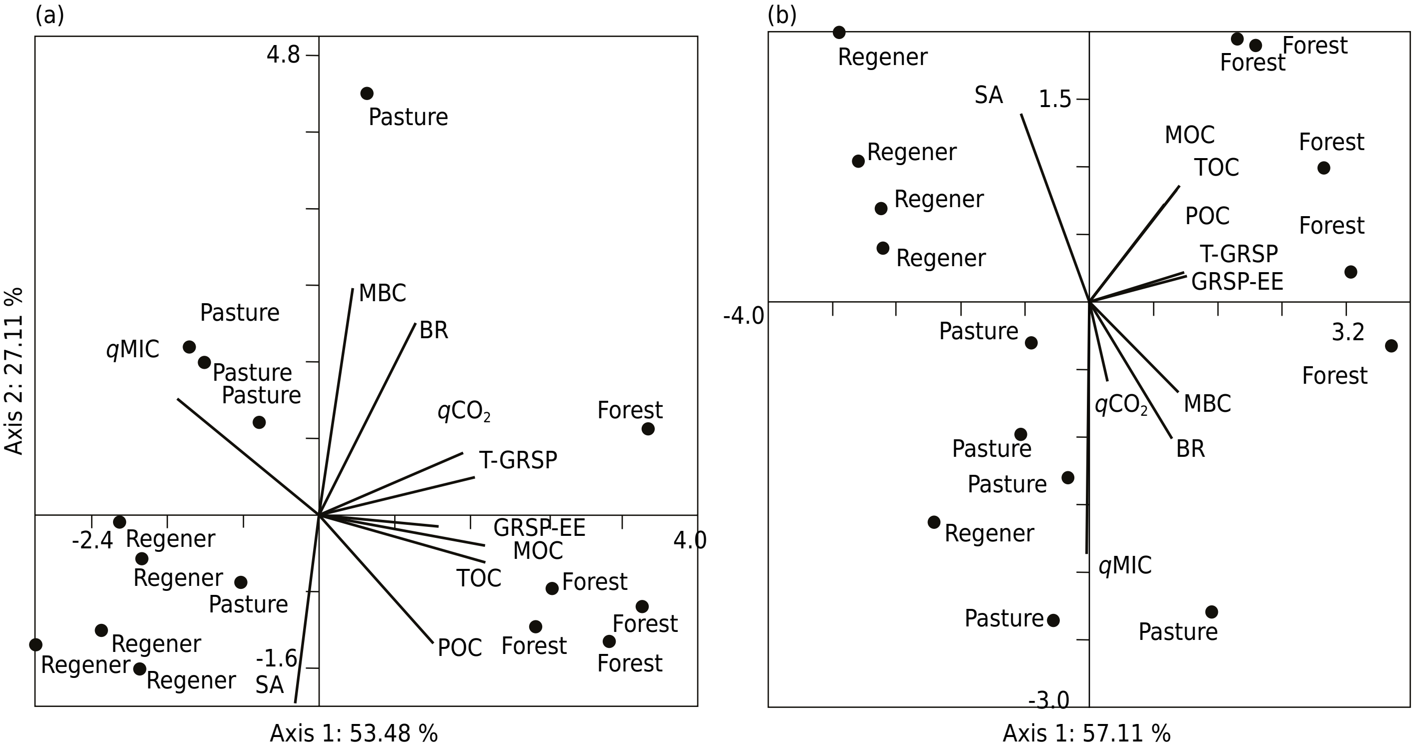

Figure 2. Ordination diagram produced by principal component analysis of topsoil properties (0.00-0.05 m) associated with organic matter and microorganisms in areas of natural regeneration (Regener.), natural pasture, and a fragment of native forest on the Palmital farm in Passa Vinte, MG, Brazil, sampled in the dry (a) and rainy (b) season. T-GRSP: total glomalin-related soil protein; EE-GRSP: easily extractable glomalin-related soil protein; BR: soil basal respiration; MBC: microbial biomass carbon, *q*CO$_2$: metabolic quotient; *q*MIC: microbial quotient; POC: particulate organic carbon; MOC: mineral associated organic carbon; TOC: total organic carbon; SA: spore abundance.

decomposition and susceptibility to degradation, in addition to the lack of disturbance by anthropogenic activity, which results in lower rates of water erosion and SOM mineralization (Cunha et al., 2012; Silva et al., 2012a)

One aspect to consider is the occurrence of outliers among the observation points in the diagram, in both seasons and especially in the pasture area. This pattern results from the higher spatial variability of pasture properties, which is likely caused by animal activity, given that it makes the pasture more heterogeneous through discontinuous and non-uniform grazing and excrement distribution (Salton and Carvalho, 2007). In a review study, Dias Filho and Ferreira (2008) report that animals tend to change nutrient cycling, affecting litter quality, nutrient concentration, organic matter, and the biological activity of soil by feces and urine deposition in the areas where they remain for longer periods (Franzluebbers et al., 2000; Rook et al., 2004; Salton and Carvalho, 2007). These processes can increase soil heterogeneity and are likely associated with the variability observed in the results, given that sample collection was random.

CONCLUSIONS

Forest conversion into natural pasture changes the biological properties of soil and organic matter dynamics, reducing total levels of organic carbon and particle size fractions (POC and MOC), abundance of arbuscular mycorrhizal fungus spores, and glomalin-related soil protein.

Microbial biomass carbon and basal respiration in the soil were not changed by the use of land as natural pasture, suggesting higher resilience of these indicators.

The fallow period in the natural regeneration area was not long enough to recover total organic carbon levels and particle size fractions of organic matter (POC and MOC), microbial biomass activity, and carbon and glomalin-related soil protein to levels close to those observed in the forest area.

Natural regeneration stimulated spore production by arbuscular mycorrhizal fungi, microorganisms with an important role in establishing and advancing the ecological succession of plant species.

Seasonal conditions affect biological properties and organic matter dynamics in soil. From the dry to the rainy season, total organic carbon, mineral-associated organic carbon, metabolic quotient, soil basal respiration, and easily extractable glomalin-related soil protein decreased, whereas microbial biomass carbon, microbial quotient, and total glomalin-related soil protein increased.

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