Changes in microbiological attributes of a Red Latosol under different cropping systems

Alterações dos atributos microbiológicos em um Latossolo Vermelho sob diferentes sistemas de manejo

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Abstract

The objective of this study was to evaluate changes in microbiological attributes of soils under different growing systems. Three cropping systems were evaluated (1) no-tillage system (NTS); (2) conventional tillage system (CTS); and (3) newly scarified no-tillage system (SNTS). The three systems were maintained for 20 years. In addition, a primary forest (PF) fragment was used as a reference. Soil samples were collected at depths of 0.0 - 0.1 m, 0.1 - 0.2 m, and 0.2 - 0.3 m. The following variables were measured: microbial biomass carbon (MBC); soil respirometry (RESP) using the fumigation and incubation method; microbial biomass nitrogen (MBN) using fumigation and extraction; metabolic quotient (qCO$_2$) using the RESP/MBC ratio; and number of spores (NS) of mycorrhizal fungi by plate counting of spores extracted from the soil by wet sieving. Treatments were arranged in a completely randomized block design with five replicates. The different management systems affected the soil microbiota, especially in the superficial layer of 0.0 - 0.1 m. At a depth of 0.0 - 0.2 m, the PF presented significantly higher values for all analyzed attributes, except for NS. There were no significant differences in the studied characteristics between the NTS and SNTS at the three depths, indicating that scarification performed only once in the NTS was not sufficient to produce changes in soil microbiological attributes. However, the adoption of the CTS for 20 years promoted a decrease in MBC and MBN. RESP and NS were not significantly different between the cropping systems. Principal component analysis indicated a significant difference in microbiological characteristics between the PF and the areas under management. Therefore, different growing systems change the soil microbiota, and the lower the degree of tilling (NTS and SNTS), the smaller the changes in soil microbiological attributes. Soil preparation practices used in conventional tilling negatively affect soil microbial biomass, decreasing the levels of MBC and MBN.
Key words: Conventional tillage. Microbial carbon. Metabolic quotient. Mycorrhizae. No-tillage.

Resumo

O objetivo deste trabalho foi avaliar alterações nos atributos microbiológicos do solo em diferentes sistemas de manejo. Avaliou-se três tipos de manejo de solo (1) sistema de plantio direto -SPD; (2)

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plantio convencional - PC, ambos estabelecidos a 20 anos e (3) sistema de plantio direto de 20 anos recém escarificado - SPDE. Além desses, um fragmento de floresta primária (FP) foi usado como referência. Amostras de solo foram coletadas nas profundidades de 0,0 - 0,1; 0,1 - 0,2 e 0,2 - 0,3 m e determinados o carbono da biomassa microbiana (CBM) e a respirometria do solo (RESP) pelo método da fumigação e incubação, o nitrogênio da biomassa microbiana (NBM) determinado por fumigação e extração, o quociente metabólico (qCO$_2$) pela razão entre RESP/CBM, e o número de esporos de fungos micorrízicos (nESP) por contagem em placa sob microscópio dos esporos extraídos do solo por peneiramento úmido. Os dados foram analisados como delineamento inteiramente ao acaso com cinco repetições. Os diferentes manejos influenciaram a microbiota do solo, destacadamente na camada superficial de solo 0,0 - 0,1 m. Na profundidade de 0,0 - 0,2 m a FP observou-se valores significativamente maiores para todos os atributos analisados, exceto nESP. O SPD e SPDE não diferiram nas profundidades para nenhum dos atributos, mostrando que a escarificação realizada apenas uma vez no SPD, não foi suficiente para produzir alterações sobre os atributos microbiológicos do solo. Entretanto, o manejo do solo em PC por 20 anos promoveu reduções no CBM e NBM. A RESP não se diferenciou entre os manejos, assim como o nESP. Na análise de componentes principais houve evidente distância, em termos de atributos microbiológicos, entre a FP e as áreas sob manejo. Conclui-se que os diferentes manejos de solo alteram a microbiota, sendo que, quanto menor a intensidade do manejo (SPD e SPDE) menores são as alterações nos atributos microbiológicos do solo. As práticas de preparo do solo usadas no plantio convencional alteram negativamente a biomassa microbiana do solo, causando reduções no CBM e NBM.

Palavras-chave: Plantio convencional. Carbono microbiano. Quociente metabólico. Micorrizas. Plantio direto.

Introduction

In the state of Paraná (Brazil), Latosols cover an area of 62,000 hectares, corresponding to 31% of the territory of the state (BHERING, 2007). These soils are basaltic, weathered, and deep. Moreover, the characteristics of these soils favor agricultural activity and allow using different cultivation and growing systems. The cropping system used is the no-tillage system (NTS), which involves crop rotation, minimum tillage, and permanent soil cover (CASÃO JUNIOR et al., 2012).

Different from the NTS, the conventional tillage system (CTS) is based on using preparation techniques that promote soil mobilization for aeration and decompaction, which consequently decreases the levels of soil organic matter (SOM) and nutrient stock, reduce soil aggregation, and affect microbial biomass (AZIZ et al., 2013; KABIRI et al., 2016).

Although the NTS uses no-tillage or minimal tillage, the use of soil scarifiers has been adopted in these areas, particularly in soils with a clayey texture, to eliminate the possible occurrence of surface compaction after using NTS for several years (ARAÚJO et al., 2004; LLANILLO et al.,

2006). Cortez et al. (2011) observed that scarification produced minimal surface tillage, which helped maintain soil coverage and prevent the inversion of soil layers. In NTS areas, the effect of scarification was evaluated by measuring soil physical attributes (ARAÚJO et al., 2004; CORTEZ et al., 2011; KABIRI et al., 2015), chemicals (RAIESI; KABIRI, 2016), water resources, and crop yield (CAMARA; KLEIN, 2005; SANTOS et al., 2008). Moreover, the effects of scarification on the soil microbiota need to be studied because this soil component is sensitive to environmental changes (OLIVEIRA et al., 2016) and is directly associated with the decomposition of SOM and nutrient dynamics (MOREIRA et al., 2011). The microbiological attributes most commonly used in soil analysis are microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial activity by soil respiration (RESP), metabolic and microbial quotient (qCO$_2$ and qMIC), enzyme activity, and the number of spores (NS) of mycorrhizal fungi (ANGELINI et al., 2012). The analysis of these attributes in agricultural areas allows determining soil quality, which in the long term reflects the sustainability of agricultural areas.

Changes in microbiological attributes in different soil cropping systems were reported by Babujia et al. (2010), who found that 20-year management of a Latosol increased RESP, qMIC, MBC, MBN, and total stocks of N and C in the NTS compared with the CTS. Santos et al. (2008) analyzed a standard Oxisol under three distinct cropping systems and observed that the NTS and scarification + leveling grid presented the highest MBC values compared with the use of a heavy grid. Raiesi and Kabiri (2016) evaluated MBC, MBN, RESP, and enzyme activity and concluded that soil quality was better in the NTS using a soil scarifier compared to the CTS. Ferreira et al. (2017) observed that MBC and qCO$_2$ values using the NTS for 5 years were similar to those in the native vegetation area. These studies demonstrate the importance of adopting conservationist farming systems that are essential for maintaining or improving soil quality. Therefore, considering that management systems affect soil microbiota and consequently soil quality,

the objective of this study was to evaluate changes in microbiological attributes of Red Latosol under different cropping systems.

Materials and Methods

Study area and sampling

The study areas corresponded to a commercial agricultural crop of approximately 400 ha located in the municipality of Bela Vista do Paraíso, State of Paraná, Brazil (22° 57' LS, 51° 11' LO). According to the classification of Köppen-Geiger, the climate of the region is type Cfa – humid subtropical and mesothermic – with a mean annual precipitation of 1,529 mm, the predominance of rainfall from October to March, mean temperature of 21.4 °C, and relative humidity of 69.9% (CAVIGLIONE et al., 2000). The soil was classified as Dystroferric Red Latosol (SANTOS et al., 2013) (Rhodic Ferralsol) with clay contente ranging from 675 to 740 g kg^{-1} (Table 1).

Table 1. Granulometric and chemical composition of a Dystroferric Red Latosol managed in a no-tillage system (NTS), scarified no-tillage system (SNTS), conventional tillage system (CTS), relative to a primary forest (PF) at depths of 0.0 - 0.1, 0.1 - 0.2 and 0.2 - 0.3 m.

Management	Granulometry				Chemical composition					
	Clay	Sand	Silt	pH	C	P	K$^+$	Ca^{2+}	Mg^{2+}	Al^{3+}
	g kg^{-1}				g dm^{-3}	mg dm^{-3}		cmol$_c$ dm^{-3}		
0.0 - 0.1 m										
PF	675	135	190	5.6	34.3	2.3	0.6	10.5	2.8	0.0
NTS	735	150	115	5.6	21.9	7.9	0.6	6.7	2.5	0.0
SNTS	735	150	115	5.5	22.8	7.5	0.5	7.4	2.9	0.0
CTS	700	125	175	6	15.8	14.5	0.7	9.2	2.7	0.0
0.1 - 0.2 m										
PF	690	130	180	5.4	22.8	0.8	0.4	7.1	2.8	0.0
NTS	730	160	110	5.7	14.8	1.2	0.2	6.9	2.2	0.0
SNTS	730	160	110	5.6	16.0	1.2	0.2	6.3	2.2	0.0
CTS	710	120	170	6.1	9.5	2.6	0.3	8.5	2.5	0.0
0.2 - 0.3 m										
PF	700	170	130	5.1	15.9	0.6	0.2	4.8	2.7	0.0
NTS	730	160	110	5.8	9.9	1.2	0.1	6.1	1.8	0.0
SNTS	730	160	110	5.7	11.8	1.4	0.1	6.0	1.7	0.0
CTS	740	130	130	5.9	8.3	2.4	0.1	9.2	2.6	0.0

pH = H$_2$O; C = Walkley- Black; P e K$^+$ = Mehlich 1; Ca^{2+}, Mg^{2+} e Al^{3+} = KCl 1,0 mol L^{-1}.

The soil cropping systems practiced in the area were the no-tillage system (NTS), conventional tillage system (CTS), and a scarified no-tillage system (SNTS), maintained for 20 years.

The area of the property under the NTS comprised 209 ha of the total area. In this area, crop was cultivated over the residues of the previous crop in a rotation system using maize (*Zea mays*), soybean (*Glycine max*), and wheat (*Triticum aestivum*) for grain harvesting; canola (*Brassica napus*), oats (*Avena sativa*), rye (*Secale cereale*), and triticale (*Triticosecale*) were cultivated as winter cover crops in alternation with wheat.

The area with the CTS occupied 190 ha, and its preparation before summer sowing in a 20-year period was based on subsoiling (~ 0.35 m) and plowing followed by harrowing (~ 0.15 m), and crop succession with corn, soybean, and wheat.

A total of 5 ha of the area under the SNTS was scarified, constituting the SNTS area, and cultivated with the same crop rotation described for the NTS area. Scarification was performed once at a depth of 0.30 m after harvesting the summer crop (soybean).

In the entire study area, soil acidity was corrected by applying 1030 kg ha^{-1} of limestone with MgO > 12% to the soil surface during the off-season (wheat/soybean) when base saturation (V%) was <50%. Fertilization was performed according to the needs of the crops following the recommendations of Raij et al. (1996).

A primary forest (PF) fragment with natural soil conditions located in the Atlantic Forest domain adjacent to the experimental area was used as a reference.

Soil samples were collected in 1-ha areas delimited in each management system and the PF. Five sampling sites were determined equidistantly and arranged in a zig-zag, and five subsamples circularly distributed around each site were collected to form a composite sample. Soil samples were collected at depths of 0.0 – 0.1, 0.1 – 0.2 and 0.2 – 0.3 m. Sampling was performed before

sowing the winter crop (wheat), which in the SNTS corresponded to a period of 30 days after scarification.

Chemical analysis

The soil chemical attributes were evaluated as described by Pavan et al. (1992). The samples were dried at 60 °C for 24 hours, then crushed and sieved in a 2-mm sieve. The levels of exchangeable Ca^{2+}, Mg^{2+}, and Al^{3+} in the soil were extracted with 1.0 mol L^{-1} of KCl. Exchangeable Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrophotometry, and Al^{3+} was measured by titration with sodium hydroxide (NaOH). Available P and exchangeable K^+ were extracted using Mehlich^{-1} extractant solution and quantified by spectrophotometry at an absorbance of 630 nm and flame photometry, respectively. Total organic carbon (TOC) was measured by oxidizing the soil using potassium dichromate ($K_2Cr_2O_7$) in sulfuric medium and subsequent titration using ferrous sulfate ($FeSO_4$). The pH was determined in a suspension of soil and distilled water at a ratio of 1: 2.5. The results of soil and chemical analyses are presented in Table 1.

Microbiological analysis

MBC was determined using the fumigation and incubation methods of Jenkinson and Powlson (1976) with modifications. Briefly, 20 grams of soil samples fumigated and non-fumigated with chloroform were incubated in the dark for 3 days at 25 °C. The released CO_2 was collected in a 1.0 mol L^{-1} solution of NaOH and quantified in the Flow Injection Analysis (FIA) system. MBC was calculated by applying a K_C of 0.45 (JENKINSON; LADD, 1981). RESP corresponded to CO_2 levels obtained from non-fumigated samples during the incubation period. The metabolic quotient (qCO_2) was obtained by calculating the RESP/MBC ratio. MBN was extracted using the method described by Brookes et al. (1985) and subsequently determined by colorimetry according to Keeney and Nelson

(1982) using a correction factor (K_N) of 0.54.

The number of spores (NS) of arbuscular mycorrhizal fungi (AMF) was quantified using the wet sieving method according to the methodology described by Gerdemann and Nicolson (1963). After extraction, the spores were washed four times in water and transferred to plates for counting in a stereoscope (400× magnification) as described by Colozzi Filho and Balota (1994), and the value was expressed as the number of spores per 50 mL of soil.

Statistical analysis

Statistical analysis was performed using software R version 3.3.3 considering a completely randomized design with five replicates. Data normal distribution was tested using the Shapiro-Wilk test, and the homoscedasticity was assessed using the Bartlett test. The treatments (NTS, CTS, and SNTS) were compared with each other using analysis of variance (ANOVA) followed by Tukey test ($p \leq 0.05$) and compared with the PF using the t-test ($p \leq 0.05$). For principal component analysis (PCA), the data were previously analyzed using the Kaiser-Meyer-Olklin test and values > 0.5 were considered as minimum adaptability (HAIR et al., 2006). The components that produced a cumulative variance of 70% were used.

Results and Discussion

At a depth of 0.0 - 0.1 m, the PF presented significantly higher values for all evaluated microbiological attributes, except for NS. Moreover, MBN, MBC, and RESP at 0.1 - 0.2 m were higher in PF (Table 2). This result is due to the dynamic equilibrium in an environment with native vegetation, which favors soil microbial biomass because of the continuous and diverse supply of organic materials (leaves, branches, and fruits) at different rates of decomposition (MOREIRA; FAGERIA, 2011; BALOTA, 2017). In addition, the accumulation of litter causes little variation in temperature and humidity (BALOTA, 2017), favoring the development and growth of microorganisms. In turn, soils subjected to agricultural activity present adverse conditions, which usually result in a decrease in the microbial population. In this study, at a depth of 0.0 - 0.1 m, this condition was reflected by a decrease in MBC by 65% in the CTS, 53% in the SNTS, and 48% in the NTS compared to the PF. At 0.1 - 0.2 and 0.2 - 0.3 m, the decrease in MBC was <40% and <35%, respectively, in all cropping systems. Lourente et al. (2010) observed a decrease in MBC of 74% in the NTS and 73% in the CTS at 0.0 - 0.1 m when native vegetation was cut for developing cultivation systems.

In the evaluated cropping systems, there were significant differences in MBN, MBC, and $q\text{CO}_2$ at a depth of 0.0 - 0.1 m and significant differences in MBC at 0.1 - 0.2 m. At 0.2 - 0.3 m, there were no significant differences in these parameters between treatments (Table 2), indicating that the soil surface layer was more strongly affected by the different management systems and corroborates the results of D'Andréa et al. (2002) and Paredes Junior et al. (2015).

Regardless of the soil depth, MBC and MBN were higher in the NTS and SNTS compared to the other systems, but these two systems did not differ from each other (Table 2). This result demonstrates the higher accumulation of C and N in NTS and SNTS areas because of the low oxidation potential. In contrast, intense tillage and low soil cover in CTS areas cause higher variations in temperature and humidity (BALOTA, 2017), promoting the oxidation of C (BAYER et al., 2003). Aziz et al. (2013) reported similar results, wherein MBC values were 2-fold higher in the NTS compared to CTS. With regard to the use of agricultural machinery, Kabiri et al. (2016) studied the use of four tillage equipment and observed that reduced tillage (using a chisel and rotary plows) caused less impact on the soil microbiota than the conventional tillage (using a moldboard and disk plows).

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Table 2. Microbial biomass nitrogen (MBN), microbial biomass carbon (MBC), respirometry (RESP), metabolic quotient ($q\mathrm{CO_2}$), and number of spores (NS) of mycorrhizal fungi in Dystroferric Red Latosol managed under a no-tillage system (NTS), scarified no-tillage system (SNTS), conventional tillage system (CTS), relative to a primary forest (PF) at depths of 0.0 - 0.1, 0.1 - 0.2 and 0.2 - 0.3 m. The values correspond to the means of five replicates.

Management	MBN	MBC	RESP	$q\mathrm{CO_2}$	NS*
	mg kg^{-1} soil		mg C-CO$_2$ kg^{-1} soil h^{-1}	mg C-CO$_2$ kg^{-1} MBC day^{-1}	spores 50 mL soil^{-1}
			0.0 - 0.1 m		
PF	259.32 A	956.98 A	4.20 A	0.10 A	1.71 A
NTS	60.64 Ba	493.60 Ba	0.45 Ba	0.02 Bb	2.00 Aa
SNTS	80.98 Ba	449.64 Ba	0.47Ba	0.03 Bb	2.75 Aa
CTS	39.24 Bb	333.54 Bb	0.85 Ba	0.06 Ba	2.96 Ba
			0.1 - 0.2 m		
PF	61.92 A	574.35 A	1.04 A	0.04 A	1.93 A
NTS	28.82 Ba	438.60 Ba	0.35 Ba	0.02 Aa	1.60 Aa
SNTS	29.97 Ba	449.20 Aa	0.40 Ba	0.02 Aa	1.73 Aa
CTS	21.23 Ba	355.29 Bb	0.29 Ba	0.02 Aa	1.71 Aa
			0.2 - 0.3 m		
PF	24.78 A	333.68 A	0.45 A	0.03 A	0.91 A
NTS	24.18 Aa	334.55 Aa	0.30 Aa	0.02 Aa	1.66 Aa
SNTS	30.52 Aa	318.52 Aa	0.46 Aa	0.03 Aa	1.73 Aa
CTS	17.05 Ba	225.43 Aa	0.38 Aa	0.04 Aa	1.48 Aa

Uppercase letters compare each tillage system with the primary forest (PF) at the same soil depth using the t-test (p≤0.05). Lowercase letters compare the soil cropping systems at the same soil depth using Tukey's test (p≤0.05). MBN values at a depth of 0.0 - 0.1 m were tested using non-parametric statistics (Kruskal Wallis test). *Data transformed into √(NS+0.5).

Microbial biomass is usually more abundant and more active in the NTS compared to the CTS (FERREIRA et al., 2010; BABUJIA et al., 2010; AZIZ et al., 2013) because of non-tillage, crop rotation due to the rhizospheric effect, and the presence of straw, which provides organic C to the microbial biomass. In addition, the NTS promotes higher aggregation and higher aggregate stability and maintains or increases the levels of organic matter (LLANILLO et al., 2006), creating habitats favorable to microbial development. In contrast, the CTS separates macroaggregates, resulting in loss of microbial habitats (KIHARA et al., 2012; KABIRI et al., 2016).

The analyzed attributes were not significantly different between the SNTS and NTS. This lack of effect is usually attributed to two reasons. In this study, scarification was performed only once and, as reported by Kabiri et al. (2016), the effect of soil tillage on microbial biomass is more pronounced when systems are established for at least 6 years. It is known that changes in soil structure directly affect microbial habitats (SILVA et al., 2014). For this reason, it is possible that microbial habitats, which originate primarily from macroaggregates, were not significantly affected in the SNTS. The second reason is that soil samples were collected 30 days after scarification and part of the microbial activity may have been reestablished in this period.

Similar results were reported by Silva et al. (2014), who evaluated the effect of soil structure on microbial biomass in a 22-year study using Red Latosol and observed that the morphologically homogeneous areas were less compact and more porous in the NTS and SNTS, which resulted in a 20% increase in MBC and 51% increase in MBN

in these two systems compared to the CTS. This result confirms the hypothesis that changes in soil structure may be correlated with changes in microbial biomass.

Principal component analysis (PCA) was used to assess the relationship between the different cropping systems and microbiological attributes of the soil. PCA results indicated that the principal components (PCs) at a depth of 0.0 - 0.1 m discriminated 92.7% of data variability (72.7% for PC1 and 20% for PC2) (Figure 1a) and that the contribution of PCs at the 0.1 - 0.2 m layer was 80.6% (Figure 1b). Figures 1a and 1b showed that the ellipse encompassing the points in the three soil management systems was associated with NS. At the 0.2 - 0.3 m layer, the contribution of PCs was 70.5% (Figure 1c) and the three cropping systems did not form a single cluster opposite to PF. MBN, MBC, and RESP were more closely grouped with the PF in the X-axis, whereas the NS was more closely group with the management systems in the Y-axis, leading to the formation of two clusters (Figure 1). The weight of the eigenvectors used in the interpretation of each PC was higher than 0.5, and this value is considered significant for PCA (Table 3). At depths of up to 0.2 m, the managed areas formed a cluster opposite to PF (Figure 1), as determined using the t-test (Table 2).

In this study, there was no difference in RESP between the soil cropping systems. However, RESP in these systems was significantly different from PF (Table 2), which had the highest mean (4.2 mg C-CO_2 kg^{-1} soil h^{-1}), indicating higher microbiological activity. This result is different from that found by Ferreira et al. (2010), wherein RESP was decreased due to soil tillage. The range of RESP values was similar to that found by Mercante et al. (2008) in the NTS and CTS in Argisols, and by Ferreira et al. (2017) in Red Latosols of the Cerrado.

The qCO_2 values were significantly different at a depth of 0.0 - 0.1 m, with values of 0.02 and 0.10 mg C-CO_2 kg^{-1} MBC day^{-1} (Table 2) in the NTS and PF, respectively. Santos et al. (2004) and Fialho et al. (2006) reported higher qCO_2 values under natural soil conditions, and this is because of the presence of easily assimilable substrates for microbial development. The qCO_2 in the CTS was 0.06 mg C-CO_2 kg^{-1} MBC day^{-1}, indicating higher CO_2 losses in this environment compared to the NTS and SNTS because the microbial population in the CTS may oxidize C for soil maintenance and adaptation (ISLAM; WEIL, 2000). Similar results were reported by Lourente et al. (2010), wherein higher qCO_2 values were obtained in the management system under the native vegetation, followed by the CTS, as observed in the present study.

There were no significant differences in NS between the cropping systems at the analyzed depths (Table 2). However, there was a significant difference in the NS between the PF and CTS. This result can be related to the chemical composition of the soil, which is strongly correlated with the presence of AMF (ANGELINI et al., 2012; BALOTA, 2017). There was a significant correlation between the NS and the levels of available P of the soil by the Spearman test (r = 0.59, p ≤ 0.05). The PF had the lowest levels of available P in the soil, and consequently lower NS (Table 1), and a similar result was observed using PCA, in which the NS was grouped in the Y-axis with the management systems (Figure 1) that presented the highest levels of available P, opposite to PF (X-axis), which had the lowest levels of available P at the three soil depths evaluated (Table 1). In addition, plowing and harrowing in the CTS, scarification in the SNTS, and the discs of the plow in the NTS during sowing can disrupt AMF hyphae by inducing sporulation, increasing the NS in managed areas. Colozzi Filho et al. (1999) reported that this result was because spores are resistance structures, and AMF subjected to stressful conditions producing spores as a survival strategy.

Figure 1. Principal components analysis (PCA) for soil microbiological attributes in primary forest (PF), no-tillage system (NTS), scarified no-tillage system (SNTS), and conventional tillage system (CTS). a, depth of 0.0 - 0.1 m; b, depth of 0.1 - 0.2 m; c, depth of 0.2 - 0.3 m.
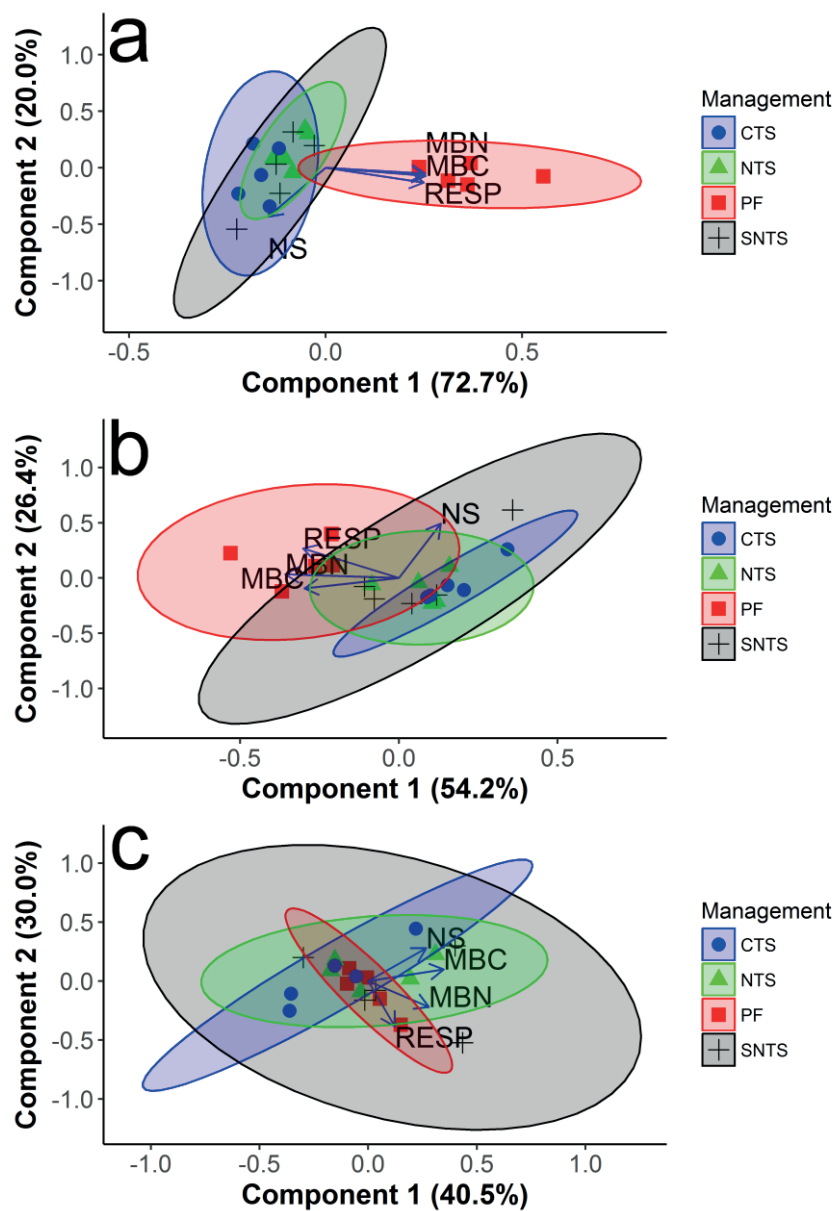
MBC = microbial biomass carbon, MBN = microbial biomass nitrogen, RESP = soil respirometry, NS = number of spores of mycorrhizal fungi. Ellipses represent the 95% confidence interval.

Table 3. Values of eigenvectors obtained in the principal component analysis for microbial biomass nitrogen (MBN), microbial biomass carbon (MBC), respirometry (RESP), and number of spores (NS) of mycorrhizal fungi.

Attributes	PC1	PC2	PC3	PC4
	0.0 - 0.1 m			
MBN	0.549	-0.113	0.817	0.133
MBC	0.552	-0.153	-0.498	0.651
RESP	0.541	-0.282	-0.282	-0.740
NS	-0.318	-0.940	—	0.100
	0.1 - 0.2 m			
MBN	-0.628	—	-0.205	0.748
MBC	-0.521	-0.165	0.813	-0.202
RESP	-0.529	0.471	-0.390	-0.588
NS	0.231	0.864	0.382	0.231
	0.2 - 0.3 m			
MBN	0.523	-0.413	0.645	0.374
MBC	0.651	0.185	—	-0.736
RESP	0.229	-0.723	-0.652	—
NS	0.500	0.522	-0.398	0.564

Underlined values (|0.5|) were considered in the interpretation of the results.

Conclusions

The different soil cropping systems evaluated change microbiological attributes of the soil, particularly in the superficial layer (0.0 - 0.1 m). This change was inversely proportional to the degree of soil tillage, and the levels of MBC and MBN were decreased whereas $q\mathrm{CO_2}$ levels were increased when the soil was subjected to conventional tillage.

Scarification performed in the no-tillage system in the first year of implantation did not affect the microbiological attributes of the soils.

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