

# Response of soil fungi and biological processes to crop residues in no-tillage system<sup>1</sup>

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## ABSTRACT

Soil management and crop rotation can directly affect the soil microbial community. This study aimed at determining soil quality indicators and soilborne fungi in a no-tillage system. A randomized blocks design, in a 3 × 2 factorial arrangement, was used. Three cover crops (palisade grass, millet and common bean) provided straw and root residues to the following crops of corn and soybean. The common bean-soybean sequence provided little soil covering and higher metabolic quotient and soil basal respiration and total enzymatic activity, as well as a general increase of soilborne fungi. The principal component analysis revealed that 76.61 % of the variance can be explained by the three first components, with cover crops, soil basal respiration and metabolic quotient regarded as the main qualitative and quantitative sources of variance in the first component. Carbon from the microbial biomass was the soil quality indicator best correlated to crop yield and negatively correlated to *Fusarium solani* density. The *Rhizoctonia solani* population was correlated with higher metabolic quotient and soil total enzymatic activity and basal respiration. The palisade grass crop favored soil fungistasis and enhancement of antagonist *Trichoderma* spp. populations. The multivariate approach demonstrated the association of soil fungi with soil quality indicators, as well as a higher influence of cover crops on the variance observed, in comparison to cash crops.

KEY-WORDS: Microbial biomass; basal respiration; suppressive soils.

## INTRODUCTION

Sustainable crop management involves the careful choice of cover crops that avoid organic matter loss and population growth of soilborne harmful microorganisms. The soil microbial community presents a vast array of fungal and

## RESUMO

Resposta de fungos e processos biológicos do solo a resíduos vegetais em sistema plantio direto

O manejo do solo e a rotação de culturas podem afetar diretamente a comunidade microbiana do solo. Objetivou-se determinar indicadores de qualidade e fungos habitantes do solo, no sistema plantio direto. Utilizou-se delineamento em blocos casualizados, em esquema fatorial 3 × 2. As três espécies de cobertura utilizadas foram braquiarião, milheto e feijão-comum, que forneceram palha e resíduos de raízes para o milho e a soja. A sequência feijão-comum + soja proporcionou pouca cobertura do solo, maior quociente metabólico e respiração basal e atividade enzimática total do solo e aumento geral de fungos de solo. A análise de componentes principais teve 76,61 % da variância explicada pelos três primeiros componentes, com as culturas de cobertura, a respiração basal do solo e o quociente metabólico considerados as principais fontes qualitativas e quantitativas de variância no primeiro componente. O carbono da biomassa microbiana foi o indicador de qualidade do solo melhor correlacionado com o rendimento das culturas, e negativamente correlacionado com a densidade de *Fusarium* spp. A população de *Rhizoctonia solani* foi correlacionada com maior quociente metabólico e atividade enzimática total e respiração basal do solo. O cultivo do braquiarião favoreceu a fungistase no solo e aumento das populações do antagonista *Trichoderma* spp. A avaliação multivariada demonstrou a associação de fungos de solo com indicadores de qualidade do solo, bem como maior influência das plantas de cobertura sobre a variância observada, em comparação com as culturas de verão.

PALAVRAS-CHAVE: Biomassa microbiana; respiração basal; solos supressivos.

bacterial species, including soil organic matter decomposers (Moreira & Siqueira 2006) and root pathogens such as *Rhizoctonia solani* and pathogenic *formae specialis* of *F. oxysporum* (Van Bruggen & Semenov 2000).

The saprophytic survival of these pathogens complicates disease management in host crops such

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as common bean (*Phaseolus vulgaris* L.) and soybean [*Glycine max* (L.) Merr.]. Theoretically, the severity of root rots and vascular wilts is proportional to inoculum density increase, in response to loss of general microbial biomass and microbial activity (Garbeva et al. 2004). Monoculture and short crop rotations decrease microbial diversity and activity (Anderson & Domsch 1989).

Sustainable practices to avoid yield losses include the boost of antagonists and biological processes to promote soil suppressiveness (Anees et al. 2010). Despite many goals on soil health reported with composts and other practices (Veeken et al. 2005), the recovery of infested fields remains challenging, especially in tropical regions where two or three annual harvests favor the buildup of a complex population of soil pathogens (Termorshuizen et al. 2006).

The conservation of helpful species and beneficial biological processes is essential to a positive balance against pathogenic microorganisms in soil, aiming toward a sustainable agricultural management. Some biochemical and biological variables can be employed as sensitive markers of environmental changes, concerning land use, and are potential tools to predict soil quality and support decision-making on crop management (Bonanomi et al. 2010). Since microbiological communities in the soil have an important role in crop development (Moreira & Siqueira 2006), it is necessary to know the impacts of agronomic practices on these communities to protect and enhance beneficial microorganisms.

Consequently, the assessment of soil key species to biological control provides relevant information that may support sustainable agricultural systems. Such assessment includes investigations on cropping sequences, cultural practices, chemical and organic pathogen control, climatic variables, microbial components and overall microbial activity in the rhizosphere, in comparison with bulk soil (Odum 1985, Pankhurst et al. 1995, Knupp & Ferreira 2011).

Many ecological relationships on soil have been described by variables assigned as quality indicators, assessed according to their chemical, physical and biological nature (Weller et al. 2002). Mulch and root residues provided by conservation tillage are important sources of nutrients and energy for the soil microbial community (Ferreira et al. 2011). In no-tillage agricultural systems, mulch and organic inputs enhance the microbial biomass and nutrient

storage, supporting increased yields in a sustainable way (Ferreira et al. 2010, Kaschuk et al. 2010).

Agricultural systems are complex. Despite the importance of individual variables, it is necessary to have a holistic view of the impacts on relevant processes to the agroecosystem (Pankhurst et al. 1995, Knupp & Ferreira 2011). There are still few reports concerning the relationships among soil quality indicators, inoculum density of biocontrol agents and root pathogens in tropical soils. Therefore, this study aimed at assessing the effects of different crop rotations under no-tillage system on some attributes of the soil biological quality indicators and their association to pathogenic and beneficial soil fungi.

## MATERIAL AND METHODS

The experiment was carried out in Santo Antônio de Goiás (16°28'00"S, 49°17'00"W and 823 m of altitude), Goiás State, Brazil. According to the Köppen classification system, the site has an "Aw" climate, tropical Savannah, mesothermal. The average annual temperature ranges from 20.6 °C to 24.2 °C, with 1,485 mm of rainfall.

The soil was classified as a dark red Dystrophic Oxisol with clayey texture. Prior to the experiment, soil samples were collected for chemical analysis at the 0-20 cm depth layer, with the following results: pH = 6.1; Ca = 2.6 cmol<sub>c</sub> dm<sup>-3</sup>; Mg = 0.9 cmol<sub>c</sub> dm<sup>-3</sup>; Al = 0.0 cmol<sub>c</sub> dm<sup>-3</sup>; H + Al = 5.1 cmol<sub>c</sub> dm<sup>-3</sup>; P = 5.8 mg dm<sup>-3</sup>; K = 218 mg dm<sup>-3</sup>; Cu = 3.6 mg dm<sup>-3</sup>; Zn = 4.2 mg dm<sup>-3</sup>; Fe = 33 mg dm<sup>-3</sup>; Mn = 51 mg dm<sup>-3</sup>. Soil organic matter was estimated in 23 g dm<sup>-3</sup>.

The experimental area was cropped in 2005/2006, adopting the "Santa Fé" system, a corn (*Zea mays* L.) and palisade grass [*Urochloa brizantha* (C. Hochstetter ex A. Rich.) R. Webster] intercropping highly used in Brazil for crop-livestock integration and no-tillage. Afterwards, the entire area was cropped with common bean in the fall/winter of 2006, followed again by the "Santa Fé" system in the summer of 2006/2007.

The layout of the experiment was a complete randomized blocks design with four replications, disposed in a 2 × 3 factorial scheme. Treatments consisted of mulch and root residues provided by the cover crops used [palisade grass, millet (*Pennisetum glaucum* (L.) R. Brown) and common bean] and two spring/summer crops (corn and soybean). The plot size was 20 m<sup>2</sup> (4 m × 5 m).

In the fall/winter of 2007, the field was divided to establish common bean, millet and palisade grass. Autumn-seeded crops were grown under sprinkler irrigation, and cultivation procedures followed regional recommendations for each specific species. Common bean was manually harvested at 90 days after planting, and grasses were herbicide-burned with 6 L ha<sup>-1</sup> (1.8 kg of acid equivalent ha<sup>-1</sup>) of glyphosate. The cover crops biomass was evaluated at soybean and corn sowing.

The soybean 'BRS Valiosa' and corn hybrid BRS 1030 were sown on November 24 (2007), 15 days after herbicide-burning the previous crops. Mulch of cover crops was sampled at the corn and soybean sowing time, for an estimate of straw dry mass. Random samples were taken twice in each plot, with a metallic grid (25 cm x 25 cm, totaling 625 cm<sup>2</sup>), between the crop rows. The straw samples were dried at 60 °C, until constant weight, to obtain mulch dry mass estimates in kg ha<sup>-1</sup>.

Soybean and corn, also referred here as cash crops, were always rainfed. The soil fertilization of cash crops followed recommendations from soil analysis and consisted of 300 kg ha<sup>-1</sup> of the 05-30-15 (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O) formulation for corn and 400 kg ha<sup>-1</sup> of 00-20-20 for soybean. Corn seeds were treated with the carbofuran insecticide (2 L of the commercial product 100 kg<sup>-1</sup> of seeds) and seeds of soybean were inoculated with Biomax (*Bradyrhizobium* spp. Semia 5079 and 5080 strains with 7.2 x 10<sup>9</sup> cfu g<sup>-1</sup>, 250 g of commercial product 60 kg<sup>-1</sup> of seeds). Cash crops were sown with row spacing of 0.90 m and 0.45 m and seeding density of 6.8 and 17 seeds m<sup>-2</sup>, respectively for corn and soybean. Manual harvest was performed separately, according to the different maturation stages, at 120 and 150 days after emergence, respectively for soybean and corn (Oliveira et al. 2013a, 2013b).

Soil sampling was carried out at the flowering stage of corn and soybean, around 60 days after emergence. Soil samples consisted of eight subsamples taken at the 0-10 cm topsoil layer from each plot and homogenized manually. The samples were immediately stored in a cooler box with ice and sent for storage in the laboratory for one week (4 °C). The soil samples were used to estimate the soil microbial biomass carbon and nitrogen, soil basal respiration, metabolic quotient and soil enzymatic activity, through hydrolysis of fluorescein diacetate hydrolysis, and the population density of soil fungi.

Microbial biomass carbon was assessed with the fumigation-extraction method by Vance et al. (1987). Briefly, each soil sample was split into six subsamples of 20 g, three of which fumigated for 24 hours with ethanol-free chloroform. Fumigated and non-fumigated samples were incubated for seven days at room temperature (22 ± 2 °C) in the dark, in individual sealed flasks containing 10 mL of 1.0 M NaOH. The CO<sub>2</sub> released during the incubation period was determined by titration of the residual NaOH, using 0.5 N HCl after carbonate precipitation with BaCl<sub>2</sub> to estimate soil basal respiration (Jenkinson & Powelson 1976). Microbial biomass nitrogen was quantified according to Brookes et al. (1985), after sulfuric acid digestion followed by Kjeldahl distillation. The metabolic quotient was estimated as described by Anderson & Domsch (1990), as was the soil basal respiration /microbial biomass carbon ratio.

Soil enzymatic activity was measured by the fluorescein diacetate hydrolysis method (Schnürer & Rosswall 1982), and consisted of the dilution of 5 g of soil in 20 mL of potassium phosphate buffer (60 mM, pH 7.6) and 0.2 mL of fluorescein diacetate (Sigma, Cat. No.7378) solution at 2 mg mL<sup>-1</sup> of acetone. The samples were shaken for 20 minutes at 170 rpm. Afterwards, 2 mL were taken from the supernatant and added to 2 mL of acetone, to stop the reaction. The solution was centrifuged for 10 minutes at 170 rpm and then subjected to spectrophotometric analysis at 490 nm.

The density of the soilborne fungi *F. solani*, *F. oxysporum* and *Trichoderma* spp. was quantified by the dilution-plating method, with semi-selective media respectively from Nash & Snyder (1962), Komada (1975) and Martin (1950). Soil subsamples of 10 g were diluted at 10<sup>-2</sup> or 10<sup>-3</sup> in distilled water and shaken at 170 rpm, for 40 minutes. The deep plating technique was used to mix 1 mL of soil suspensions to their respective culture media. *Rhizoctonia solani* density was estimated by the percentage of colonized organic residues in water-agar media (Weinhold et al. 1977). Petri dishes were incubated in the dark for seven days at 20 °C ± 2, for colony counting.

One-way analysis of variance and Tukey test at 5 % were performed with GLM procedure from the SAS 9.1 statistical software (SAS Institute, Cary, NC, USA). In addition, the principal component analysis (PCA) was carried out to verify the relationship between all soil quality indicators and soil fungi, and to check the relevance of each variable on total

variance. Cover and cash crops were addressed as supplementary variables to help data analysis, with no influence on the principal components (Lê & Husson 2008). PCA was carried out with FactoMineR and Rcmdr packages from the R 2.15 statistical software (R Development Core Team, Vienna, Austria).

## RESULTS AND DISCUSSION

The cover crops used here generate different amounts of straw distributed over the soil, as previously reported by Oliveira et al. (2013b). Palisade grass generates 7,792 kg ha<sup>-1</sup>, millet 5,371 kg ha<sup>-1</sup> and common bean 4,926 kg ha<sup>-1</sup> of straw. The amount and composition of the cover biomass affected soil quality indicators and soilborne fungi, along with cash crops yield. Millet and common bean provided higher soybean grain yield (4,772 kg ha<sup>-1</sup> and 5,200 kg ha<sup>-1</sup>, respectively), while the soybean yield was 3,708 kg ha<sup>-1</sup>, when grown after palisade grass (Oliveira et al. 2013a). Corn yield was higher after common bean (8,133 kg ha<sup>-1</sup>), differing from millet (6,601 kg ha<sup>-1</sup>) and palisade grass (6,801 kg ha<sup>-1</sup>) (Oliveira et al. 2013b).

Fluorescein diacetate hydrolysis ranged between 101 and 147 mg of FDA hid kg dry soil<sup>-1</sup> h<sup>-1</sup>, indicating a difference in soil enzymatic activity among the different treatments (Table 1). The soil enzymatic activity was significantly higher for common bean, if compared to palisade grass. There was no difference between corn and soybean crops, considering the averages of soil enzymatic activity, and maize was not affected by the preceding cover

crop. Only soybean was responsive to soil enzymatic activity differences among cover crops, with the highest average observed under common bean straw, followed by millet and palisade grass.

Microbial biomass carbon showed significant differences among cash crops, cover crops and their interaction (Table 1). The microbial biomass carbon ranged 100-236 mg C kg<sup>-1</sup> of dry soil, while microbial biomass nitrogen values ranged 37-52 mg N kg<sup>-1</sup> of dry soil. Regarding cash crops, corn yielded the highest average of microbial biomass carbon. Such increase was favored especially in plots previously cropped with palisade grass, in which microbial biomass carbon was 127 % higher than in the common bean-soybean sequence. Millet also promoted microbial biomass carbon, which was 53.7 % higher than in the common bean-soybean sequence. In addition, microbial biomass carbon is improved by the cropping of perennial forage species (Stromberger et al. 2007), such as palisade grass, used in this study.

Previous cropping of millet favored higher microbial biomass nitrogen in corn (Table 1), despite the fact that common bean has lower C:N ratio and aids endemic soil bacteria (Thébault et al. 2014). According to Nascente et al. (2013), millet residues provide a rapid release of N to the soil, when compared to palisade grass, what supports our results. There was no difference between corn and soybean, regarding microbial biomass nitrogen. The eventual benefits on nitrogen inputs from cover crops were irrelevant in treatments with soybean, possibly as a result of soybean seeds being inoculated with *Bradyrhizobium* spp.

Table 1. Soil enzymatic activity (SEA), total microbial activity, carbon (CMB) and nitrogen (NMB) from the microbial biomass, soil basal respiration (SBR) and metabolic quotient ( $q\text{CO}_2$ ) estimated for cover crops and following cash crops in no-tillage system.

Factor	SEA (mg <sup>1</sup> FDA <sup>a</sup> hid kg <sup>-1</sup> dry soil h <sup>-1</sup> )		CMB (mg C microbial kg <sup>-1</sup> dry soil)		NMB (mg N microbial kg <sup>-1</sup> dry soil)		SBR (mg of C-CO <sub>2</sub> kg <sup>-1</sup> dry soil h <sup>-1</sup> )		$q\text{CO}_2$ (mg C-CO <sub>2</sub> g <sup>-1</sup> C-mic h <sup>-1</sup> )	
<i>Cover crop</i>										
Palisade grass	109.9 B*		143.9 A		35.6 B		0.39 C		0.95 C	
Millet	130.1 AB		102.2 B		48.6 A		1.79 A		2.49 B	
Common bean	137.4 A		158.2 A		41.2 AB		1.63 B		4.11 A	
<i>Cash crop</i>										
Corn	125.9 A		166.6 A		42.3 A		1.08 B		2.05 B	
Soybean	126.8 A		103.1 B		43.3 A		1.45 A		2.98 A	
<i>Cover x cash crop</i>										
	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean
Palisade grass	118.8 Aa	101.2 Cb	236.1 Aa	51.95 Cb	37.7 Ba	39.4 Aa	0.53 Ca	0.25 Bb	0.74 Ba	1.15 Ca
Millet	128.9 Aa	131.3 Ba	159.7 Ba	156.8 Aa	51.9 Aa	45.4 Ab	1.50 Ab	2.08 Aa	2.05 Aa	2.93 Ba
Common bean	127.1 Ab	147.8 Aa	103.9 Ca	100.6 Ba	37.5 Ba	44.9 Aa	1.23 Bb	2.03 Aa	3.35 Ab	4.87 Aa

\* Means followed by the same capital letter in the column or same lowercase letter in the line do not differ by the Tukey test at 5 %. <sup>a</sup>FDA: fluorescein diacetate.

Differences for soil basal respiration and metabolic quotient were observed among cash crops, cover crops and their interaction (Table 1). Palisade grass cropping decreased soil basal respiration and metabolic quotient in both cash crops. On the other hand, the metabolic quotient increased after millet and common bean. These soil biological activity traits increased with soybean cropping, in comparison with corn. Lower metabolic quotient and soil enzymatic activity found in sequences with palisade grass may be related to the higher biomass and lower decay of *U. brizantha* mulch (Oliveira et al. 2013a, 2013b), negatively correlated with general soil microbial activity. Similar results were observed in native vegetation (Ferreira et al. 2010, 2011). In contrast, the higher metabolic quotient observed in the common bean-soybean sequence indicates increased activity of soil microorganisms (Van Bruggen & Semenov 2000). Some authors, such as Odum (1985), associate increased soil respiration with environmental stress, but, in the present study, we regard soil respiration as an indicator of a transformation ability of the soil microbiota, in response to cropping sequences (Silva et al. 2013).

Palisade grass was unfavorable for *Fusarium* spp. and *R. solani*, in contrast to millet and common bean (Table 2). The populations of *F. solani* and *F. oxysporum* were higher under soybean, when compared to corn. Regarding cover crops, the highest populations were found under millet for *F. solani* and under common bean for *F. oxysporum*. Mulch and root residues of palisade grass favored increases in the density of the biocontrol agent *Trichoderma* spp.

(Figure 1), suggesting benefits of such cover crop on the management of fungi associated to root diseases.

The common bean-soybean sequence provided favorable conditions for higher density of *R. solani*, in contrast to the treatments with millet or palisade grass. The present results showed that *R. solani* was the fungal species that best supported the increased soil activity, in contrast to *Trichoderma* spp. Naturally, many other fungal or bacterial species might have responded to the treatments studied here, but our study was restricted to the relationships among *Fusarium*, *Rhizoctonia* and *Trichoderma* and soil quality indicators. Furthermore, palisade grass straw was the only effective cover crop to significantly decrease, in the short-term, all fungal populations related to root

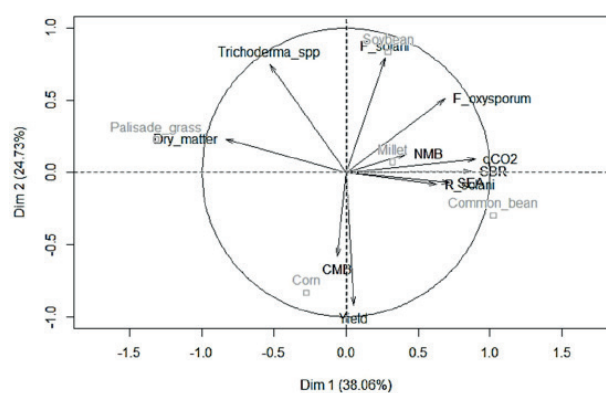


Figure 1. PCA biplot with relationships found in the first two components, between soil quality indicators and soilborne fungi, assessed in a no-tillage system. Cover crops (palisade grass, millet and common bean) and cash crops (soybean and corn) were addressed as supplementary variables.

Table 2. Effects of cover crops and cash crops on soilborne fungal population in no-tillage system.

Factor	<i>Fusarium solani</i>		<i>Fusarium oxysporum</i>		<i>Trichoderma</i> spp.		<i>Rhizoctonia solani</i>							
	PPG x 1,000													
Cover crop														
Palisade grass	3.70 B*		2.78 B		9.28 A		2.49 B							
Millet	5.03 A		3.80 A		4.20 B		4.99 AB							
Common bean	3.00 B		4.68 A		0.93 C		10.55 A							
Cash crop														
Corn	2.22 B		2.15 B		1.47 B		4.62 A							
Soybean	5.60 A		5.22 A		8.13 A		7.40 A							
Cover crop x cash crop														
Palisade grass	Corn	2.60 Ab	Soybean	4.80 Ba	Corn	2.05 Ba	Soybean	3.10 Ca	0.75 Ab	17.80 Aa	Corn	3.33 Aa	Soybean	1.66 Ba
Millet	Corn	3.05 Ab	Soybean	7.00 Aa	Corn	3.20 Ab	Soybean	4.40 Ba	2.35 Ab	6.05 Ba	Corn	3.33 Aa	Soybean	6.66 Aba
Common bean	Corn	1.00 Bb	Soybean	5.00 Ba	Corn	1.20 Bb	Soybean	8.15 Aa	1.30 Aa	0.55 Ca	Corn	7.22 Aa	Soybean	13.88 Aa

<sup>a</sup>PPG: propagules per gram of soil; <sup>b</sup>% ORC: percentage of organic residues colonized; \* means followed by the same capital letter in the column or same lowercase letter in the line do not differ by the test t at 5%.

diseases in soybean. Population decline is one of the mechanisms of soilborne pathogen control based on crop residues (Bonanomi et al. 2010). Even though pathogenicity tests were not carried out here, the implementation of no-tillage with palisade grass is expected to help the management of *R. solani* and *F. oxysporum* (Toledo-Souza et al. 2008).

Despite the relevant benefits of palisade grass in decreasing pathogen populations, it is important to note that it decreased the subsequent soybean yield in crop rotation (Oliveira et al. 2013a). It is unclear what are the factors that lead to soybean decreased leaf area index and number of pods per plant, resulting in lower yield after palisade grass crop rotation.

Principal component analysis indicated clear differences between effects provided by cover and cash crops on soil quality indicators and fungi density, in which 76.61 % of the variance was explained by the three main components (38.06 %, 24.73 % and 13.82 %) (Figure 1). The multivariate approach attended the recommendations by Janvier et al. (2007) to identify soil health indicators. Cover crops had a higher correlation (0.72) with the first component, while cash crops were mostly correlated (0.81) with the second principal component (Table 3). As the microbial activity variables were mostly correlated with PC1, these correlations indicate that mulch might have a stronger influence on microbiological density and activity than cash crops.

Table 3. Results of the principal component analysis including cover crops, cash crops, soil quality indicators and soilborne fungi assessed in no-tillage system, with significance of  $p < 0.05$ .

Variable	PC1	PC2	PC3
Eigenvalue	4.20	2.70	1.50
% of variance	38.06	24.73	13.82
% of cumulative variance	38.06	62.79	76.61
Cover crop <sup>a</sup>	0.72	ns	0.38
Cash crop <sup>b</sup>	ns	0.81	ns
Yield	ns	-0.92	ns
Dry matter (mulch)	-0.83	ns	ns
Soil enzymatic activity	0.72	ns	ns
Microbial biomass carbon	ns	-0.57	0.66
Microbial biomass nitrogen	0.41	ns	0.68
Soil basal respiration	0.87	ns	ns
Metabolic quotient	0.90	ns	ns
<i>Fusarium solani</i>	ns	0.79	0.41
<i>Fusarium oxysporum</i>	0.68	0.51	ns
<i>Trichoderma</i> spp.	-0.52	0.74	ns
<i>Rhizoctonia solani</i>	0.63	ns	ns

<sup>a</sup> palisade grass, millet and common bean; <sup>b</sup> corn and soybean.

There were positive correlations of soil enzymatic activity, microbial biomass nitrogen, basal soil respiration, metabolic quotient, *F. oxysporum* and *R. solani* with the first principal component ( $p < 0.05$ ), while dry matter and *Trichoderma* spp. were negatively associated with PC1 (Table 3). *Fusarium* species and *Trichoderma* spp. were associated with PC2, while yield and microbial mass carbon were negatively correlated with the second principal component of the PCA.

As aforementioned, the balance between putative pathogens and antagonists is not easily controlled and depends on several factors that include chemical and physical variables, in addition to changes in the soil microbial community (Pérez-Piqueres et al. 2006, Toledo-Souza et al. 2008). Such balance is expected to change with cumulative effects of cover crops, if no-tillage is maintained in a cropping system. For this reason, the correlations of soil quality indicators with the inoculum density of pathogens and antagonists reported here demonstrate immediate effects in the first year after the implementation of the no-tillage system. Long-term trials are recommended to investigate further consequences that might affect decisions for crop management in a conservationist approach (Table 3).

Although many soil fungi and bacteria affect soil suppressiveness to root diseases, some endemic species may have a key role over soil pathogens (Liu & Baker 1980). In our study, relevant soil fungi were affected by cover crops, and palisade grass favored *Trichoderma* spp., in contrast to *R. solani*. These results reinforce the recommendations of palisade grass to the management of soilborne pathogens in no-tillage systems (Toledo-Souza et al. 2008). Palisade grass is a well-known grass for pastures under tropical climate, because of the high dry matter yield, lignin content and C/N ratio and low decomposition rate. It is one of the main sources of mulch to no-tillage systems, in Brazil (Nascente et al. 2013, Oliveira et al. 2013a, 2013b).

This study showed correlations among soil quality indicators, soilborne fungi, yield and both cover and cash crops. Agronomic practices required for crop management, such as grass herbicide-burning and common bean manual harvest, may affect plant  $\times$  soil  $\times$  microorganism relationships, and therefore treatment effects discussed here rely not only on the crop itself, but also on standard cropping methods. Apparently, these results are the first ones on the relationships among microbial biomass

carbon and nitrogen and soil enzymatic activity with *Trichoderma* spp. and *Fusarium* spp. They are in agreement with Bonanomi et al. (2010), regarding the positive correlation between soil respiration and *R. solani* and the beneficial effects of crop residues on this pathogen suppression.

Besides the increment of endemic *Trichoderma* spp., it is possible that a high C/N ratio and lignin content of palisade grass promote other suppression mechanisms of *R. solani*, such as beneficial *Streptomyces* spp. and basidiomycetes responsible to microsclerotia decay (Postma et al. 2008, Van Beneden et al. 2010). Changes in the microbial community can improve fungistasis and decrease populations of some pathogens. It is noteworthy that the increase of soil basal respiration was related to cover crops with lower C/N ratio (Table 1), where faster straw decomposition rate and loss of CO<sub>2</sub> in common bean and millet might have changed soil fungistasis based on the competition hypothesis (Bonanomi et al. 2013).

Our results described how the sequences of cover crops and cash crops in one agricultural year affect the balance between different soil biological attributes, in a tropical region. Regardless of differences in temperature and rainfall, they also match the literature from countries with Mediterranean or temperate climate (Termorshuizen et al. 2006, Bonanomi et al. 2013). It is possible that different responses from fungal species and microbial processes arise in long-term sequences, and microbial community structure and other indicators could provide further relevant information on soil health.

Among the different cover crops assessed here, palisade grass is recommended as the best option for soybean and maize crop management, since it provides higher amount of dry mass and is likely to keep long-lasting mulch on the soil surface (Nascente et al. 2013). Besides the benefits on soil and water conservation, palisade grass straw minimizes soil microbiological activity and might help the management of fungal soilborne pathogens.

## CONCLUSIONS

1. Crop sequences in a no-tillage system affect the balance between different soil biological attributes.
2. Palisade grass minimizes soil microbial activity and might favor soil health with increase of endemic *Trichoderma* spp.

3. Common bean and millet are positively associated with higher density of *R. solani* and *F. oxysporum* and increased microbial activity (soil basal respiration, metabolic quotient and soil enzymatic activity).

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