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Biological Quality Indicators of a Haplortox Soil Under Different Management Systems in Southern Brazil

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Abstract

The research was looking for the quick response of soil's microbiota to soil changes caused by management systems, changes to which biological indicators of soil quality are sensitive. In this context, this study aimed to evaluate the impacts of seven soil management systems, including in on hand covers of *Pennisetum glaucum* (PG), *Avena strigosa* (AS), *Stizolobium aterrimum* (SA), EF *Pisum sativum* (PS) + *Avena strigosa* (AS), and on the other hand, No soil tillage with gypsum application (NTSG), No soil tillage with scarification (NTSS) and No soil tillage (NTS), on soil quality bioindicators. The bioindicators recorded from top soil samples were collected from the first 10 cm at pre-planting, at pre-flowering and at post-harvest of the soybean, from July 2014 to March 2015 were Total organic carbon (TOC), Soil microbial biomass carbon (SMBC), Soil basal respiration, Respiratory coefficient ($q\text{CO}_2$), Microbial coefficient (qMIC), and its relationship with soybean yields. The seven treatments were arranged in the field according to a completely randomized experimental, Analysis of variance (Anova) for each of the bioindicators and comparison of treatment mean values using Tukey test at 5% probability were carried out. SA, the AS+PS consortium and the no-tillage system led to significant improvement of the biological attributes of the soil. The management systems did not change the yield of soybean grain.

Keywords: soil microbial biomass carbon, soil organic matter, soybean yield

1. Introduction

The soil microbiota is responsible of the maintenance of ecosystems through their action in the biogeochemical cycles, as well as their performance in soil formation and structuring, nutrient cycling and organic matter decomposition (Souza et al., 2006).

The productivity of a crop is directly proportional to the amount of microbial biomass of the soil, microbial population and activity are altered according to the soil management, in some cases, having a deleterious effect on it, and thus, considered an important soil quality indicator (Perez, Ramos, & McManus, 2004; Legaz et al., 2017).

Currently, the use of green manure in a no-tillage system has become increasingly important for the improvement of the soil's biological, physical and chemical attributes. These species must possess high resistance to temperature variations and rainfall levels, roots with high vigor, ease of elimination and non-competition with the subsequent crop, to cycle nutrients (Dessalew et al., 2017), among others; for these reasons, the two main groups of cover plants are the *Fabaceae* (leguminous plants) and the *Poaceae* (grasses) (Foloni, Lima, & Bull, 2006; Carneiro et al., 2008).

Representatives of the *Fabaceae* family have their use established because they reincorporate nitrogen to the soil that is fixed biologically through the bacteria of the *Rhizobium* and *Bradyrhizobium* genera, in addition to their high rate of decomposition resulting from the low value of the C/N ratio, which is less than 20, thus rapidly cycling nutrients (Carneiro et al., 2008).

The high C/N ratio of *Poaceae* family members, which varies between 30 and 40, guarantees their greater permanence in the soil, contributing to a greater protection of the soil with the formation of straw, which also acts as a reserve of nutrients with slow degradation and; its abundant roots act directly on the soil structure, maintaining the stabilization of the aggregates (Carneiro et al., 2008).

In this scenario, the cultivation of cover crops increases its importance in the soil, since they soften the physical, chemical and biological alterations that the soils undergo at each crop (Silva et al., 2010).

Studies have demonstrated that microbial biomass and its activity act as more sensitive indicators to changes in soil structure and quality, caused by soil management systems (Trannin, Siqueira, & Moreira, 2007).

The objective of this study was to evaluate the impact of seven different management systems on microbiological attributes of soil quality and its effects on soybean yield.

2. Material and Methods

2.1 Experimental Area and Soil

The research was carried out at the experimental station of the Agronomic Institute of Paraná (IAPAR), located in the municipality of Santa Tereza do Oeste, Paraná State. The region's geographical coordinates are longitude 53º29′37″ W and latitude 24º50′42″ S. Its altitude is 750 m above sea level and climatic classification, according to Koppen, is humid subtropical (cfa). The annual average precipitation is 1840 mm. The soil is classified as typical Haplortox with a clay texture, smooth-wavy terrain, and basalt substrate as well (Embrapa, 2013).

2.2 Field Establishment of the Experiment

As treatments, three soil management systems were used in an area managed with no soil tillage for 18 years (no-tillage system-NTS; no-tillage system with gypsum application-NTSG and no-tillage system with scarification-NTSS) and four other treatments with cover plant species: consortium with *Avena strigosa* (AS) and *Pisum sativum* subsp. *arvense* (PS); *Avena strigosa* (AP); *Pennisetum glaucum* (PG) and *Stizolobium aterrimum* (SA). A seed-fertilizer was used with lagged double-disc type trencher mechanism, with no base fertilization and/or coverage for the planting of cover plant species (Table 1). Treatments arrangement is shown in Figure 1.

Table 1. Timetable of field activities

Dates	Activities
3/27/2014	Seeding of summer cove plant species
7/17/2014	Seeding of winter cover plant species
7/10/2014	Application of gypsum (1 application)
10/20/2014	Soil scarification (1 scarification)
11/7/2014	Soybean seeding
3/11/2015	Soybean harvest

T5 No-tillage system with gypsum (NTSG)	T3 *Stizolobium aterrimum* (SA)	T4 *Avena strigosa* + *Pisum sativum* subsp. *Arvense* (AS+PS)	
T1 *Pennisetum glaucum* (PG)	T2 *Avena strigosa* (AS)	T6 No-tillage system with scarification (NTSS)	T7 No-tillage system (NTS)

Figure 1. Sketch of the experimental area and arrangement of treatments. The experimental units consisted of plots of 20 m × 25 m

The no-tillage system with gypsum consisted of the application of 3000 kg ha^{-1} of gypsum on the surface. In the no-tillage system with scarification, the scarification was up to 0.30 m deep.

Cultural practices for the control of weeds (N-(phosphonomethyl)-glycin—4 L ha^{-1}), pests (Bifenthrin + carbosulfan—0.3 L ha^{-1}) and diseases (fluxapyroxad + pyraclostrobin—0.3 L ha^{-1} + Soy oil methyl ester 0.25% v.v.) were carried out in the according to technical recommendations for soybean culture, using a tractor/hydraulic sprayer set with a capacity of 600 L and 14m-spray bar. Soil fertilization was carried out with 300 kg ha^{-1} of NPK formulation 02-20-20. 16 seeds per linear meter of cultivar Vmax NK 7059 RR of soy were sown in rows with 0.45 m spacing.

The experimental design was completely randomized design. Soil samples were collected in three periods: pre-planting, pre-flowering and post-harvesting of soybean, from July 2014 to March 2015, in four replications for each experimental plot, totaling 12 samples in each treatment.

Samples for microbiological analysis of the soil and the soil's biota respiratory activity were collected in the 0-0.10 m layer at three randomly selected sites, where the vegetable material layer was removed. The soil was collected with a paddle and conditioned in 0.10 m × 0.25 m plastic containers suitable for the collection of soil samples, which were transferred immediately after collection to the laboratory for processing and storage in a refrigerator at 4 ºC.

2.3 Variables Determined

The determination of total organic carbon (TOC) was done according to the Walkley-Black technique (Embrapa, 1999).

The values referring to the soil microbial biomass carbon (SMBC) were obtained according to the protocol for the Fumigation - Extraction methodology (Embrapa, 2007).

The soil's basal respiration (SBR) was evaluated following the protocol described by Embrapa (1999).

The metabolic coefficient ($q\mathrm{CO_2}$) is the ratio between SBR and SMBC, expressed in mg C – CO_2 g Cmic h^{-1}, defined by the formula:

$$(q\mathrm{CO_2}) = \mathrm{SBR/SMBC} \tag{1}$$

Where, SBR = C – CO_2 = Value of basal respiration; SMBC = Carbon value of soil microbial biomass.

The microbial quotient (qMIC) is the ratio between SMBC and TOC, expressed as a percentage, calculated according to the formula:

$$(q\mathrm{MIC}) = \mathrm{SMBC/TOC} \tag{2}$$

Where, SMBC = Carbon value of soil microbial biomass; TOC = Total organic carbon.

For soybean yield, grains were collected from 4 rows of 2.5 meters, totaling 4.5 m^2 with four replications per plot. The harvest was carried out with a plot harvester, and the moisture was corrected to 13%.

2.4 Statistical Analysis

Statistical analysis was performed using Assistat® 7.6 beta software, 2012 version (Silva, 2012). The analysis carried out was: an analysis of variance (Anova) for TOC, SMBC, BSR, qCO2, and qMIC and a comparison of treatment mean values for the above parameters measured using Tukey test at 5% probability.

3. Results and Discussion

3.1 Microbiological Soil Properties and Soybean Yield

The average values of microbiological soil properties between management systems and coverage species are shown in Table 2.

No statistically significant differences were found for TOC in management systems (Table 2). This lack of difference probably occurs when the soil has living vegetation coverage, where the soil temperature becomes more constant and there is less water loss from the soil to the atmosphere, thus maintaining the organic carbon, avoiding it from being lost in the form of CO_2 to the atmosphere (Barros, 2013).

The higher TOC values refer to the condition of environmental stability of the soil that the coverage, in the living case, provides; such as decrease of thermal and humidity variations, as well as a more favorable environment for the proliferation of the microorganisms than the period with the straw alone and after mechanization of the area (Barros, 2013).

Table 2. Average values of three seasons evaluated for the microbiological soil properties between management systems and coverage species

Biological attributes	Treatments									
	PG	AS	SA	AS+PS	NTSG	NTSS	NTS	LSD	Average	CV (%)
TOC (g kg^{-1})	31.2a	29.1a	31.2a	31.0a	31.3a	29.7a	30.7a	3.67	30.61	9.69
SMBC (mg C g^{-1} soil)	99.3b	76.7b	198.5a	173.15a	96.47b	158.34a	173.57a	54.34	177.37	31.55
BSR (mg C-CO_2 g^{-1} soil h^{-1})	0.65a	1.17a	1.08a	0.84a	1.46a	1.14a	1.00a	1.16	1.74	89.36
qCO_2 (mg C-CO_2 mg^{-1} cbms h^{-1})	6.43bc	15.58a	4.80c	4.80c	14.8ab	6.20bc	6.31bc	8.80	18.21	84.59
qMIC (mg $g^{-1}$$q$mic)	32.29b	26.74b	65.24a	55.45a	31.79b	53.81a	57.68a	20.69	68.40	36.31

Note. Averages of treatments followed by the same letter in the row do not differ statistically from each other by the Tukey test at the 5% level of significance. PG: *Pennisetum glaucum*, AS: *Avena strigosa*, SA: *Stizolobium aterrimum*, AS+PS: *Avena strigosa* + *Pisum sativum*, NTSG: No-tillage system with gypsum, NTSS: No-tillage system with scarification, NTS: No-tillage system, LSD: Least Significant Difference, CV: Coefficient of Variation (%), TOC: total organic carbon, SMBC: microbial biomass carbon of the soil, BSR: basal respiration of the soil, qCO_2: respiratory coefficient, qMIC: microbial coefficient.

Pereira et al. (2010) state that TOC is a sensitive indicator to changes in the micro habitats of the soil, through the alteration in the management systems; in treatments with coverage, they provide their TOC increase and reduction in the absorption of phosphorus from the soil. Increased soil mobilization reduces carbon stocks and when *Pennisetum glaucum* (PG) is used as coverage, it generates a deeper incorporation of carbon into the soil.

In the studies by Cunha et al. (2011), in treatments with coverage plants in bean and corn crops, there were no statistical differences between the management systems regarding soil TOC content, in the 0.00-0.10 m layer, data which is also evidenced in the work by Almeida et al. (2008), where it covered the soil for three years in the following systems: fallow, *Crotalaria juncea*, *Cajanus cajan*, *Pisum sativum* and *Pennisetum glaucum*, and Sousa Neto, Andrioli, and Beutler (2008), analyzing *Crotalaria juncea*, *Pennisetum glaucum* and lablabe (*Dolichus lablab*) in a period of four years.

There is a statistical difference for the SMBC indicator, and the treatment that had the highest SA with 198.5 mg C g^{-1} dry soil and the lowest AS value with 76.7 mg C g^{-1} dry soil. As expected, since the representatives of the *fabaceae* family provides the SMBC elevation of the soil, due to symbiotic associations in its roots. Duarte et al. (2014), in their studies with biological indicators of soil quality and coverage plants, verified that the highest value of SMBC was recorded in the treatment with *Crotalaria juncea*, however, finding values close to the other coverages. Cultural residues at the soil surface increase substrate availability, higher water availability, lower thermal amplitude, providing a more stable and favorable environment to BMS (Castro-Filho et al., 2002; Franchini et al., 2007; Bayer et al., 2002; Pereira et al., 2007). Several studies refer to the beneficial effects of legumes for the enrichment of SMBC in soil, due to its N_2 biofixation capacity (Ferreira et al., 2000; Franchini et al., 2007).

For SBR there was no significant statistical difference between treatments. Alves et al. (2011), Cunha et al. (2011), Duarte et al. (2014), and Dadalto et al. (2015) found no significant differences between management systems and this biological attribute. However, Nascimento et al. (2009) found significant differences between management systems. Carneiro et al. (2008), studying management systems with different coverages, high values of qCO_2 were observed in the uncovered system, demonstrating, in this area, the loss of carbon in the form of CO_2 to the atmosphere, characterizing stress in the microbial population, however, the areas covered with residues of *Crotalaria juncea* and *Cajanus cajan* had the lowest values of qCO_2, characterizing a beneficial effect from the residues of these coverages for the microbial population of the soil.

There was statistical difference for the qCO_2, where the highest value was that of treatment AS 15.58 mg C-CO_2 mg^{-1} SMBC h^{-1} and the lowest was that of treatments SA and EF, both with 4.8 mg C-CO_2 mg^{-1} SMBC h^{-1}. High qCO_2 values represent disturbances or stress in the ecosystems (Bardgett, & Saggar, 1994). In a study in which they evaluated several species of coverage and their action on BMS, Carneiro et al. (2008), noticed high values of qCO_2 in the fallow management, demonstrating the loss of carbon in the form of CO_2 to the atmosphere, characterizing stress in the soil biota.

For the qMIC attribute there was difference, with the highest value being verified in the SA 65.24 mg g^{-1} qMIC and the lowest in the AS 26.74 mg g^{-1} qMIC. High values of qMIC characterize high levels of organic carbon in the soil, and low values demonstrate soil carbon loss over a given period (Mercante et al., 2004). The qMIC is influenced by several factors, such as the management history in the study area and the degree of stabilization of organic C (Silva et al. 2010). Cunha et al. (2011) observed the highest value of *q*MIC in the treatment with *Pisum sativum* and *Stizolobium aterrimum* in relation to crotalaria and fallow.

Several studies have shown that green coverages with legumes associated with low soil mobilization lead to increased contents of SMBC (Franchini et al., 2007).

The *Stizolobium aterrimum* is indicated to be used as green manure due to its characteristic of improving the fertility and texture of the soil and by its inhibitory effect of nematode species (Ferraz et al., 2003).

Average values of soybean yield (Mg ha^{-1}) in management systems and soil coverage species in Table 3.

Table 3. Average values of soybean yield (Mg ha^{-1}) in management systems and soil coverage species

Treatments									
PG	AS	SA	AS+PS	NTSG	NTSS	NTS	LSD	Average	CV (%)
3.02a	2.96a	2.70a	2.86a	2.91a	2.93a	2.67a	573.7	2.81	87.1

Note. Averages of treatments followed by the same letter in the row do not differ statistically from each other by the Tukey test at the 5% level of significance. PG: *Pennisetum glaucum*, AS: *Avena strigosa*, SA: *Stizolobium aterrimum*, AS+PS: *Avena strigosa* + *Pisum sativum*, NTSG: No-tillage system with gypsum, NTSS: No-tillage system with scarification, NTS: No-tillage system, LSD: Least Significant Difference, CV: Coefficient of Variation (%).

Even before the improvement of the soil's biological attributes, the yield of soybean grains did not present statistical difference between the treatments (Table 3).

Pereira et al. (2011) observed in a typical eutrophic Red Latosol, where they applied *Avena strigosa* and *Pennisetum glaucum* as coverage, that there were no statistical differences for the yield of soybeans between the straw desiccation seasons. Ricce, Alves, and Prete (2011), in a study on a dystroferric Red Latosol, whose areas were covered with grazing, *Avena strigosa* and ryegrass, found no difference in soybean grains yield.

In the studies by Santos et al. (2014), in area with coverage plants, no difference was observed in the soybean grain yield during the period when the study was carried out, 1996/1997 to 2010/2011.

Santos et al. (2013), found no significant difference between coverage plants, as for the grain yield, however, after the vetch crop, the soybeans that were planted obtained the highest number of pods, number of grains and grain mass per plant than those that were sown in the other systems. Brancalião et al. (2015) statistically demonstrated that, in areas with coverage, the grain yield was higher than the areas left in fallow, stating that the fact that the soil coverage in winter alone already provides gains in soybean productivity. The differences were not observed in the soybean productivity, probably for two reasons: first, because the study area is an experimental station, the soil is maintained under high levels of fertilization; the second probable reason was the occurrence of a high and constant rainfall index in the region during the soybean development cycle.

4. Conclusion

Stizolobium aterrimum (SA), the *Avena strigosa* (AS) + *Pisum sativum* (PS) consortium and the no-tillage system (NTS) are the most indicated species and system for the improvement of the biological attributes of the soil; To increase the TOC of the soil, we recommend the use of the treatments: *Pennisetum glaucum* (PG), SA, AS+PS and NTS; There was a soil microbial biomass carbon (SMBC) increase in the treatments: SA, AS+PS, NTS and no-tillage system with scarification (NTSS); To reduce soil basal respiration (SBR), the most suitable treatments are PG, PS, NTS, NTSS and AS; In the respiratory coefficient (qCO_2) the SA, the AS+PS consortium and the TSS had lower values in the three evaluated periods; To increase the microbial coefficient (*q*MIC) the recommended treatments were SA, AS+PS, NTS and NTSS.

Species and management systems did not interfere with the soybean grain yield.

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