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Soil quality in two coffee crop systems in the Amazon biome

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ABSTRACT: The form of occupation of the state of Rondônia, Brazil, favored the extensive agriculture, which resulted in a fast deforestation. The removal of forests and inadequate soil management and use, combined with a hot and wet climate, affected the soil chemical, physical, and biological attributes. In search for less impacting and alternatives that promote greater soil conservation for coffee production in the North region of Brazil, the objective of this work was to evaluate the effects of two coffee crop systems on the soil chemical and microbiological attributes. The treatments consisted of a shaded coffee crop (SCC) and a full-sun coffee crop (FCC). A completely randomized design was used, with four clusters per treatment and seven sampling points per cluster, which constituted a replication, totaling 28 replications per treatment. The data were collected in April 2018, in a rural property in the municipality of Cacoal, state of Rondônia, Brazil (11°21'50"S, 61°20'10"W, and altitude of 238 m). The soil organic matter, pH, P, K, Ca, Mg, Al, H+Al, base saturation, and basal respiration were determined. The soil under SCC had higher Ca content, pH, and base saturation, and lower potential acidity (H+Al) and Al content than that under FCC. The litterfall on the soil under FCC presented higher N and Mg contents. The soil basal respiration increased in the first 5 cm depth in the treatment with SCC.

Key words: *Coffea canephora*, shading, sustainability

Qualidade do solo em dois sistemas de cultivo do cafeeiro no domínio Amazônico

RESUMO: A forma de ocupação do Estado de Rondônia, favoreceu a agricultura extensiva, o que resultou em desmatamento acelerado. A retirada da floresta, o manejo e uso inadequado do solo, associado ao clima quente e úmido afetaram os atributos químicos, físicos e biológicos dos solos. Buscando alternativas menos impactantes e de maior conservação do solo para produção de café na região Norte, objetivou-se nesta pesquisa avaliar os efeitos de dois sistemas de cultivo do cafeeiro, sobre a qualidade química e microbiológica do solo. Os tratamentos foram cultivo sombreado (CS) e a pleno sol (CPS). O delineamento estatístico utilizado foi o inteiramente casualizado, com quatro aglomerados para cada tratamento e sete pontos amostrais em cada aglomerado que constituem as repetições, totalizando 28 repetições para cada tratamento. A coleta de dados ocorreu em abril de 2018 em uma propriedade rural do município de Cacoal, RO, localizada a 11° 21' 50" S e 61° 20' 10" O, e altitude de 238 m. A matéria orgânica (MO), pH, fósforo (P), potássio (K), cálcio (Ca), magnésio (Mg), H + Al³⁺, alumínio (Al³⁺), saturação por bases (V) e a respiração basal do solo (RBS) foram determinados. O solo sob CS tem maior teor de Ca, pH e V (%) e menor acidez potencial e Al³⁺, em comparação ao CPS. A serapilheira sob CPS apresenta maiores teores de N e Mg e a respiração basal do solo aumentou no sombreamento nos primeiros 5 cm de profundidade.

Palavras-chave: *Coffea canephora*, sombreamento, sustentabilidade



INTRODUCTION

Coffee crop is important for rural proprieties with family basis in the state of Rondônia, Brazil; however, there is a greater focus on this activity in some periods because of the high price of coffee beans, and a lower focus on some periods due to the low prices. Considering this context, agroforestry systems have been introduced, and those focused on ecological and economic benefits and on sustainability (Rodrigues et al., 2015) have been established.

Shaded coffee crops grown in environments within the Atlantic Forest biome showed higher leaf area, number of branches, leaf nitrogen content, green fruit percentage, plant height, canopy diameter, number of leaves in the branches, and distance between nodes than coffee crops grown under full sun, without decreasing yield (Ricci et al., 2011). Pinto Neto et al. (2014) evaluated biomass and yield of coffee plants under different shading systems and found that a mean shading (68%) is more adequate to coffee crops than intense shading (84%).

Soil chemical, physical, and biological quality indicators are related to organic matter contents (Han et al., 2016), which has important functions in the complexation of substances, and supplying and storage of nutrients and water for the plants (Pezarico et al., 2013). Therefore, the adoption of management systems that increase stocks of organic residues in the soil or in the soil surface are essential to maintain and improve the soil quality (Stefanoski et al., 2013).

Thus, the objective of this work was to evaluate the effects of two coffee crop systems on the soil chemical and microbiological attributes.

MATERIAL AND METHODS

The municipality of Cacoal, state of Rondônia, Brazil, was selected for this study because it presents 3,814 agricultural properties, from which 1,391 are coffee producers, and 53% of the rural properties have coffee crops in Cacoal, and a total of 4,683 hectares of its area is grown with coffee plants (IBGE, 2017). The most common soil class found in the region is Ultisol, with medium to clayey texture.

The climate of the whole state of Rondônia is Am (monsoon), according to the Köppen classification, with mean annual rainfall depths of 1,400 to 2,600 mm and mean air temperature of 24 to 26 °C (Alvares et al., 2013).

The study was conducted at a rural property in Cacoal (11°21'50"S and 61°20'10"W, and altitude of 238 m). Two areas with coffee plants were chosen for the study (Figure 1), which were managed differently and defined as follows: Treatment 1 = soil cultivated with an agroforest system with coffee plants (*Coffea canephora*) and teak (*Tectona* sp.), which was called shaded coffee crops (SCC); and Treatment 2 = soil cultivated with coffee crops at full sun, which was called full-sun coffee crop (FCC).

The plants of the full-sun coffee crop were planted with spacing of 3 m between rows and 2.5 m between plants. The soil had been fertilized annually with mineral fertilizers consisting of N (48 kg ha⁻¹ of N), P (12 kg ha⁻¹ of P₂O₅), and K (48 kg ha⁻¹ of K₂O), without considering the soil chemical analysis. Weeds were controlled using a grass cutter machine and applications of glyphosate herbicide. The area was irrigated using a sprinkler system to promote the anthesis of the flowers. The coffee crops had never been renewed since the planting; however, the branches of the plants in the FCC had been pruned once a year, after the coffee harvest, and thinned manually twice a year in the rainy period.

Each coffee crop system (SCC and FCC) was divided into four clusters of 24 × 27 m, encompassing seven soil sampling points, which constituted the replications, totaling 28 replications per planting system.

Soil samples of the 0-5 and 5-10 cm layers were collected and sieved in 2-mm mesh sieves. Part of these samples were used to determine the soil basal respiration, and other part was air-dried to obtain the bulk soil for the analyses of organic matter content (Walkley-Black method), pH (in solution of CaCl₂), and P, K, Ca, and Mg contents (resin method), acidity potential (H+Al; determined in a SMP buffer solution), and Al content (Raij et al., 2001).

The soil basal respiration was quantified in 50 g of soil, which were placed in glass jars with a flask in the center containing 10 mL of NaOH 0.1 M; the jars were then

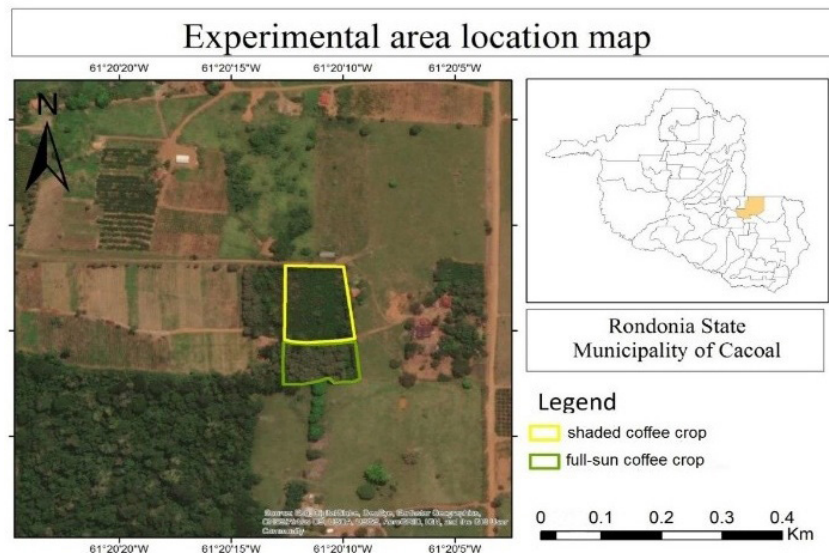


Figure 1. Location of the site selected for the study, with soils under shaded coffee crop and full-sun coffee crop

hermetically closed. The incubation time was 173 h. HCl (0.1 M) and phenolphthalein (1%) was used as indicator for titration of free NaOH. The control was prepared in glass jars without soil, containing flasks with NaOH. The titration of the free base allowed the calculation of the quantity of CO₂ that reacted with the NaOH and, thus, the C-CO₂ released by the microbial respiration (Silva et al., 2007).

Litterfall samples were collected in both treatments, totaling eight replications per area. These samples were dried at 65 °C until constant weight, ground in a mill, and used to determine the N, P, K, Ca, Mg, and S contents, following the methodology described by Malavolta et al. (1997).

The results were subjected to the Shapiro-Wilk normality test, using the R program (R Core Team, 2015). The results of organic matter (0-5 cm), P, pH (5-10 cm), Ca (5-10 cm), Mg, and H+Al (5-10 cm) presented no normal distribution and were transformed to log(y). Subsequently, the data were subjected to the F test by analysis of variance for each layer evaluated, using the Sisvar 5.6 program (Ferreira, 2014).

RESULTS AND DISCUSSION

The organic matter contents in both treatments and soil layers evaluated were similar (Table 1); however, in SCC there was senescence of teak leaves, which formed a thick litterfall layer on the soil, and in FCC there was residues of the pruning (orthotropic and plagiotropic branches, and leaves), which also form a litterfall layer contributing, similarly, to add organic matter to the first 10 cm of soil in both crop systems.

The similarity between organic matter contents in this case can be attributed to the absence of pruning residues and to the higher microbial activity in SCC (Table 2). Moreover, the plant biomass in this treatment presents lower C to N ratio (Acosta et al., 2014) due to the teak leaves, which, combined to the temperature and humidity conditions, lead to a faster mineralization of the organic matter (Guimarães et al., 2017). These factors caused less or similar organic matter contents in the soil under SCC than those in the soil under FCC, where the pruning residues resulted in a plant biomass with probably higher C to N ratio and lower microbial activity (Table 2).

Monoculture systems such as FCC are more susceptible to decreases in organic matter contents due to a lower constant deposition of organic materials on the soil. This denotes the positive effect of agroforest systems over time (Ilany et al.,

Table 2. Basal respiration (SBR) of soils under full-sun coffee crop (FCC) and shaded coffee crop (SCC), sampled from the layers 0-5 and 5-10 cm

Cultivation systems	Depth (cm)	
	0-5	5-10
	(CO ₂ mg kg ⁻¹ d ⁻¹)	
SCC	18.22 a	7.07 a
FCC	16.71 b	6.94 a
CV (%)	14	27
F Values	5.22*	0.07 ^{ns}

Means followed by the same lowercase letter in the columns, within the same layer, are not different by the F test at p ≤ 0.05

2010). This effect was not found in the present study, probably because of the evaluation time, which was in the beginning of autumn.

The phosphorus contents in the treatments were different, with higher contents in FCC, where the soil has been fertilized annually with P by surface applications. This favored the high contents of this nutrient, since it is little mobile in the soil (Iwata et al., 2012). Hagggar et al. (2011) also found significantly higher P contents in coffee crops cultivated under full sun, when compared to coffee plants under shaded systems, due to fertilizer applications.

The treatments had no effect on K contents in any of the evaluated soil layers (Table 1), despite the application of 48 kg of K₂O ha⁻¹ year⁻¹ in the FCC area and lack of soil fertilization in SCC, denoting the maintenance of K contents in SCC by means of nutrient cycling, probably because of the presence of litterfall (Lima et al., 2015).

The Ca content in the 0-5 cm soil layer in SCC was higher than that in FCC. However, no differences were found between the treatments in the 5-cm layer. However, the magnesium contents in the two soil layers analyzed was higher in FCC (Table 1), and varied from medium to satisfactory for the development of most crops (Ribeiro et al., 1999) in both SCC and FCC.

The base saturation was higher in SCC in the 0-5 cm soil layer, not differing from that in FCC in the 5-10 layer (Table 1); this can be attributed to the presence of litterfall and nutrient cycling, whose efficiency is dependent on the litterfall quality, time, crop system established, and biotic and abiotic factors (Acosta et al., 2014).

The potential acidity (H+Al) and Al contents were higher in FCC. The base saturation was higher in the 0-5 cm soil

Table 1. Organic matter (OM), phosphorus (P), pH, exchangeable bases (K, Ca, and Mg), potential acidity (H+Al), Al, and base saturation (V) in soils under full-sun coffee crop (FCC) and shaded coffee crop (SCC), sampled from the layers 0-5 and 5-10 cm

Cultivation systems	OM (g dm ⁻³)	P (mg dm ⁻³)	pH (CaCl ₂)	K	Ca	Mg	H + Al	Al	V (%)
	0-5 cm								
SCC	41.9 a	10.1 b	5.4 a	0.24 a	7.2 a	1.3 b	2.5 b	0.02 b	77.1 a
FCC	41.5 a	20.5 a	4.9 b	0.22 a	5.6 b	1.5 a	3.9 a	0.12 a	64.6 b
CV (%)	4.5	19.7	4.9	27.6	20.5	8.8	18.3	94.7	9.7
F Values	0.06 ^{ns}	14.6**	45.0**	1.3 ^{ns}	18.6**	8.6**	84.8**	31.2**	45.6**
	5-10 cm								
SCC	27.5 a	6.1 b	5.1 a	0.23 a	3.8 a	0.8 b	3.0 b	0.10 b	60.8 a
FCC	27.8 a	18.8 a	4.9 b	0.20 a	3.7 a	1.0 a	3.7 a	0.15 a	56.2 a
CV (%)	4.4	34.2	3.6	31.3	8.9	10.9	5.0	56.7	15.7
F Values	0.3 ^{ns}	14.0**	7.1*	2.7 ^{ns}	0.03 ^{ns}	8.2*	22.6**	5.82*	3.46 ^{ns}

Means followed by the same lowercase letter in the columns, within the same layer, are not different by the F test at p ≤ 0.05; CV = Coefficient of variation; ns = not significant, ** = significant at p ≤ 0.01, and * = significant at p ≤ 0.05 by the F test

layer, and similar between treatments in the 5-10 cm layer (Table 1). The soil pH was lower in FCC, which reflects the higher presence of H+Al in this management system. Iwata et al. (2012) found increases in pH and decreases in aluminum saturation in agroforest systems when compared to FCC, and attributed these results to the soil organic matter, whose function is to complex free H⁺ and Al³⁺ cations and add bases that increase the soil pH. However, considering the similar organic matter contents found in SCC and FCC, the lower presence of H⁺ and Al³⁺ in SCC can be explained by the release of bases due to a faster mineralization of organic matter, since no presence of lignified branches was found, only leaves.

Neves et al. (2007) found decreases in aluminum saturation and maintenance of pH in areas using intercrops with coffee plants, but reported that external nutrients are needed in intercrops to avoid soil chemical degradation. Ilany et al. (2010) found higher susceptibility to lowering of soil fertility over time in monocultures under agroforest systems.

The soil under SCC presented higher Ca content and pH and lower H+Al, even though it had no pruning residues and no external soil fertilization or liming, denoting the efficiency of the system in to maintain and improve the soil chemical quality.

The K, Ca, and S contents in the litterfall of the treatments SCC and FCC were similar (Figure 2); however, the N and Mg contents in the litterfall were higher in FCC, whereas P was higher in SCC, although with similar concentrations - 0.92 g dm⁻³ for SCC, and 0.69 g dm⁻³ for FCC. The nutrient content in the litterfall is usually dependent on the species present in the site, plant characteristics, and soil nutrient availability (Schumacher et al., 2004).

Nutrient concentrations (g dm⁻³) in the litterfall in the treatment SCC followed the order Ca > N > K > S > Mg > P, and in the treatment FCC it was Ca > N > Mg > K > S > P, based on estimates of amount of nutrients that will be added to the soil after the litterfall decomposition. Due to the translocation of some nutrients from leaves to other plant organs before their senescence, senescent leaves usually present higher Ca and Mg contents than N, P, and K contents (Boeger et al., 2005), which was found in the present study, except for nitrogen (Figure 2).

The soil under SCC presented higher basal respiration than that of the soil under FCC (Table 2), which is a result

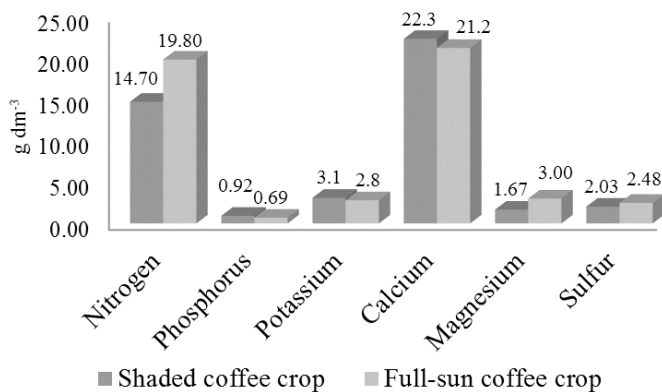


Figure 2. N, P, K, Ca, Mg, and S contents in the litterfall collected on soils under full-sun coffee crop (FCC) and shaded coffee crop (SCC) in the late summer of 2017/2018

represented by a higher CO₂ release in the 0-5 cm soil layer. This denotes the occurrence of higher microbial activity in the shaded environment. The higher microbial activity in SCC can be attributed to the higher amount of leaves on the soil due to their senescence, either from coffee plants and the arboreous species, which occurs mainly in dry periods to minimize the effects of low water availability (Villa et al., 2015). These leaves form a thick layer that maintains the soil moisture and decreases the soil temperature (Silva et al., 2012; Pezarico et al., 2013; Silva et al., 2016; Guimarães et al., 2017).

This cover with plant residues formed on the soil creates a favorable environment to the development of microorganisms (Cunha Neto et al., 2013; Guimarães et al., 2017). Soils under agroforest systems present higher microbial activity than those under annual crops due to their organic matter quality in addition to microclimate factors higher soil moisture and low soil thermal amplitude that results in more stable temperatures (Silva et al., 2012). The association of coffee plants with teak in the present study was promising regarding increases in microbial activity; however, it was restricted to the first 5 cm of soil (Table 2).

According to Silva et al. (2016), water availability and temperature are the main controllers of the soil CO₂ efflux. In the Amazon biome, the higher controller of this seasonal CO₂ efflux is the soil water availability due to the low temperature variations over the year. Moreover, another factor is the composition of plant species, since it provides a favorable microclimate and participates in the addition of carbon.

Coffee crops intercropped with *Tabebuia* sp., *Musa* spp., and *Acacia* sp. presented similar microbial activity to those found for native vegetation, and higher than those found for coffee plants in single crops (Guimarães et al., 2017). This is consistent with the significant difference between the coffee plants intercropped with teak and the coffee plants in single crops under full sun. Guimarães et al. (2017) reported that coffee plants intercropped with other species presented higher soil basal respiration due to a higher quantity of residues from a biodiversity of plants, which stimulates the activity of microorganisms.

Another factor that contributed to the higher soil basal respiration in SCC in the surface layer, when compared to the FCC, is the herbicide application, which was done in FCC to control weeds; this management was not necessary in SCC. Melloni et al. (2013) compared different methods for weed control (manual hoeing, rotary tiller, harrowing, no hoeing, pre-emergence herbicide, and post-emergence herbicide) and found intermediate negative impact on biological attributes in coffee plants when applying pre-emergence herbicide, and higher negative effect on the interrow of coffee plants when applying post-emergence herbicide.

The soil basal respiration in the crop systems evaluated presented no significant difference in the 5-10 cm layer; however, the basal respiration in this soil layer was lower when compared to the surface layer (Table 2). This confirms the dependency of microbial activity on the presence of soil organic matter (Pinto Neto et al., 2014; Oliveira et al., 2015).

CONCLUSIONS

1. The soil under the shaded coffee crop had higher Ca contents, pH, and base saturation, and lower potential acidity and aluminum content than that under the full-sun coffee crop.
2. The litterfall under the full-sun coffee crop presented higher nitrogen and magnesium contents.
3. The soil basal respiration was higher in the first 5 cm of the soil and was higher in the that coffee crop under shade.

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